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SOME RECENT DEVELOPMENTS AT LEADVILLE.

A LEADVILLE FISSURE VEIN.

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INTRODUCTION.

Ever since the appearance of S. F. Emmons's classical report upon the Leadville district the attention of geologists and mining men has been directed frequently toward that locality, and it is probable that information concerning the ore deposits of Leadville is more widely disseminated than is true in the case of any other mineralized area.

Heated controversies have arisen over questions involving the origin of these ores, and definite information on such topics has always been gladly welcomed. As Leadville has recently entered upon an era of increased activity, there appears to be a double reason for calling the attention of scientists to some recent developments there.

LOCATION OF THE FEATURES DESCRIBED.

One of the most interesting of these recent developments has been the discovery of an economically important fissure vein extending downward through and below the sedimentaries. This is known as the New Monarch, Cleveland, or Louemma vein. This body of ore has a northerly strike, and is located some distance east of most of the great properties that have given Lead-

ville a world-wide fame. Mining operations upon this vein have been carried on extensively south of South Evans Gulch, and some work has been done on this deposit through the Silver Spoon shaft, just north of the gulch.

Several rather vague descriptions of this ore body have appeared in print, but the statements made therein appeared so improbable that the writer eagerly accepted the privilege of examining the Louemma mine when the opportunity to do so was offered by Mr. Warren F. Page, the manager of the property. While most of the facts given in this paper are the result of observations made during that examination, a number of interesting and important points were gleaned from information furnished by Mr. Page.

CHARACTER OF THE COUNTRY ROCK.

The general nature of the country rock is indicated on the accompanying section. The various sedimentaries and intrusives differ in no way from the same rocks as found in other parts of the district. The intrusives are so altered where exposed that it is impossible to determine their exact nature megascopically, but they are probably the so-called "gray porphyry."

The lowest rock shown on the section is a coarse-grained granite which develops facially at some points into a granite-porphyry; perhaps it would be better to call it a porphyroidal granite. The porphyroidal appearance is due to the presence of idiomorphic orthoclase in crystals an inch or more in length.

OCCURRENCE OF THE ORE.

The ore occurs in sharply defined fault-fissure veins on both sides of a sheeted and brecciated zone, which itself contains some ore, and in small lenses east of, and parallel to, the sheeted zone.

The mineral bearing solutions followed openings and lines of weakness produced by faulting, but many closely spaced fractures were formed instead of a single one, producing the sheeted zone and the fault fissures just mentioned. All of the fractures are nearly vertical, and the sum of the displacements of all the faults amounts to about sixty feet.

Although the faulting was distributed over a zone of some width, the greatest movement evidently occurred along the western side of this zone, producing a sharply defined fault-fissure which subsequent mineralization has transformed into a fine vein of high grade ore. This is customarily called the hanging-wall vein. A smaller, less continuous fault-fissure vein of lower grade ore is found on the eastern side of the sheeted zone, and is called the foot-wall vein.

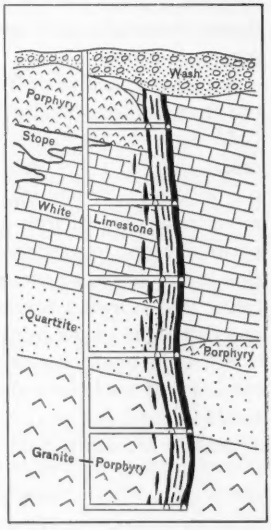

FIG. 39. Idealized cross-section through Louemma shaft and vein, Leadville, Colorado. (Solid black is ore of good grade.)

THE HANGING-WALL VEIN.

The hanging-wall vein contains the ore that gives this deposit economic importance. In width it varies from a few inches up to two or three feet, pinches being uncommon. Such evidences of faulting as slickensiding and gouge are common. That the width and grade of this vein is sufficient to permit profitable mining is indicated by the fact that the management paid $70,000 in royalties last year.

CHARACTER OF THE ORE IN THE HANGING-WALL VEIN.

To a depth of about one hundred feet the ore is completely oxidized, but the grade is not materially different from that of the material mined at greater depths, excepting that the lead content is somewhat higher. Below the one hundred-foot level there is a gradual transition from oxides to sulphides, but the former persist—mostly as tenorite—down to the five hundred-foot level. This black oxide of copper is said to be very rich in gold and silver.

The unoxidized ore is mainly black sphalerite with varying proportions of galena, pyrite, and chalcopyrite. It is an interesting and suggestive fact that the proportion of pyrite and chalcopyrite is greater in the sixth level than above that point. No diminution in the gold and silver content of the ore is yet apparent, however.

A complete analysis of a picked specimen of galena-sphalerite ore from the four hundred-foot level gave the following results: Gold, 8 ounces per ton; silver, 27 ounces per ton; lead, 29.5 per cent.; zinc, 11.1 per cent.; silica, 32.8 per cent.; manganese, 0.4 per cent. By figuring the lead to galena, the copper and the requisite amount of iron to chalcopyrite, the rest of the iron to pyrite, the zinc to sphalerite, the silica to quartz, and the manganese to pyrolusite, an excess of over two per cent. is shown, indicating that at least a portion of the copper is present as tenorite, and that some of the iron is present in the sphalerite as FeS.

Below the oxidized zone the vein filling is usually as completely composed of sulphides and quartz as the above mentioned analysis would indicate, but small horses of country rock and some kaolin or sericite are occasionally encountered.

THE FOOT-WALL VEIN.

The foot-wall vein is similar in general character to the one just described but its width or grade is not usually such as to permit profitable mining. Its width and importance have been somewhat exaggerated on the sketch accompanying this paper.

THE SHEETED ZONE.

The sheeted zone has been called "porphyry" in all the descriptions so far published and is thus termed locally. This is, however, an error into which the miners have been led by the general appearance of the material, which consists of a very white mass containing darker particles. Close examination shows that the zone is composed mainly of hydrated and softened country rock, so altered as to possess little or no resemblance to its original appearance, and of angular fragments of quartz. Occasionally

a considerable mass of less altered rock occurs. At a depth of over 450 feet this zone is principally kaolin and quartz.

The whole mass is full of nearly vertical partings and contains some precious metals, although visible ores of these are usually absent, and the value of the gold present rarely exceeds $10.00 per ton.

ASSOCIATED ORE LENSES.

Several lenticular masses of ore are shown to the left (east) of the veins and sheeted zone on the accompanying sketch. Exact data concerning their number and proportions is unavailable, but it is probable that these have been somewhat exaggerated on the section. Whether similar lenses exist west of the main ore body is unknown since that ground has not been prospected.

The ore is often of high grade but the dimensions of these masses are usually too small to give them any economic importance. In general, the lenses appear to be most numerous and of highest grade close to the veins and sheeted zone.

REPLACEMENT DEPOSITS.

The accompanying section shows stopes along the limestone-porphyry contact and down in the limestone itself. No attempt was made to obtain data from which the exact dimensions and locations of these could be shown, but their general position and geological relationships are as indicated. In the last mentioned particular, as well as in dimensions, grade and general nature and appearance of ore, and in all other features, the material removed from these stopes was identical with the sulphide replacement deposits common in the district.

These ore bodies were mined several years before anyone suspected the existence of a vein in close proximity to them, and there is no apparent connection between the vein and the replacement deposits. The limestone-porphyry contact was tight for a distance of some fifty feet from the vein, and the grade of the replacement deposits was higher at some distance from, than it was where closest to, the vein. The grade also varied with the distance from the contact, being highest where closest thereto.

CONDITIONS ELSEWHERE ON THE SAME VEIN.

The writer has had no opportunity to examine the vein in any but the Louemma mine, but others who have enjoyed this privilege report that conditions to the south are very similar to those described here, with the exception that both the displacement by faulting and the thickness of the sedimentary rocks are greater. In the Silver Spoon mine, just across the gulch to the north of the Louemma, a fault with a displacement of over a hundred feet was encountered two hundred feet east of the vein.

BEARING OF THE FACTS STATED UPON THE QUESTION OF THE ORIGIN OF THE REPLACEMENT DEPOSITS.

J. Alden Smith, while state geologist of Colorado in 1881 and 1882, claimed that all the ore ascended through fissures in the underlying granite. He wrote:[1]

"These fissures and deposits will be extensively and profitably worked for centuries after the contact deposits (He meant the replacement deposits) are exhausted."

In 1885 Emmons said:[2]

"The study of these deposits has shown . . . 4, that the ore currents from which they were deposited did not come directly from below, but were more probably descending currents; and 5, that these currents probably derived the material of which the ore bodies are formed mainly from the porphyry bodies which occur at horizons above the blue limestone."

This statement was so frequently and severely criticized by geologists and mining engineers that he was forced to defend his ideas. This he attempted to do by claiming that his earlier statements had been misconstrued in subsequent publications. He said:[3]

"In some of these the writer is assumed to have stated . . . that the metallic contents of these waters were derived from the overlying white porphyry."

Since the white porphyry is certainly "a porphyry body oc-

[1] *Mining and Scientific Press*, Vol. XCV., p. 401.
[2] Mon. XII., U. S. G. S., p. xxix.
[3] *Loc. cit.*

curring above the blue limestone," such an interpretation of his statement appears inevitable.

In his defense, Emmons modifies his original statement as follows:[1]

> "The original contention that the ores are genetically connected with the eruptive rocks seems abundantly confirmed and even strengthened by the developments of the last twenty-five years."

The phrase "genetically connected with eruptive rocks" may be interpreted in so many fashions as to leave his meaning still doubtful, but all his writings give the impression that he still believed in the essential correctness of his original statement, *i. e.*, that the "ores were derived mainly from the neighboring eruptive rocks," presumably as magmatic emanations. He justified his adherence to this theory on the ground that no ore solution channels down into the granite had been discovered, and he refused to admit the probability of a conclusion based upon unproven assumptions.

The existence of at least one such channel has, however, now been definitely proven, and A. A. Blow has shown[2] that the southern Iron Hill ore bodies are associated with cracks and broken and fissured zones. Also, it is well known that there is a decided linear arrangement of the deposits elsewhere on Iron Hill and also on Breece Hill. It is undeniable that the so-called "fissure theory" of J. Alden Smith has been greatly strengthened by the discovery of these facts, although no one believes that it is capable of as wide and economically important application as he attempted to make.

The fact that there is no apparent connection between the vein described here and the replacement deposits is an unfortunate weakness that must not be overlooked but which is not, however, fatal to the truth of the theory. It is at least possible (1) that such visible connection filled with ore has been overlooked; (2) that for some reason no ore was deposited along the channel connecting the vein and the replacement ores, if such a passage-

[1] *Loc. cit.*

[2] T. A. I. M. E., Vol. XVIII., p. 145.

way exists; (3) that the vein described was a feeder for replacement ores along some of the upper contacts now removed by erosion, and has no connection with these ores near it; or (4) that ore solutions may have risen through the vein, spread laterally along higher contacts now removed by erosion, descended through small fissures or joints, spread laterally along the lower contact, and deposited the replacement ores where now found.

The presence in the vein of appreciable quantities of all the elements found in the replacement ore certainly points to the existence of some connection between the two.

THE FISSURE THEORY OF THE ORIGIN OF THE SULPHIDE REPLACEMENT ORES.

In conclusion, the writer offers a brief statement of a modification of the fissure theory of the origin of the sulphide replacement ores of Leadville. This he believes to be substantially the one accepted by a majority of the mining engineers and geologists familiar with the district, since it is simple in conception and conforms with observed facts.

1. After the deposition of the sediments, the intrusion of the various porphyries occurred, this material rising in the molten condition from igneous masses below any depth yet reached by the mines.

2. At some later date ore-bearing solutions (doubtless heavily charged with gases) rose through vertical or inclined fissures, porous zones, or combinations of these.

3. It seems probable that the ore-bearing solutions represent an extreme type of differentiation of the magma from which the porphyry intrusions were derived. In this sense the ores may be "genetically connected with the eruptive rocks."

4. The upward movement of the solutions may have taken place through clean-cut fissures produced by earth stresses, through openings at the contacts of dykes and sediments resulting from the shrinkage of the former while cooling, or through porous zones where joint planes were unusually numerous.

5. At certain horizons the solutions encountered nearly hori-

zontal lateral lines of weakness (the various contacts) along which they flowed, and away from which they sometimes spread vertically depositing their metallic contents by metasomatic replacement of the country rock, usually limestone. The extent of this lateral spreading may have been very great, and replacement deposits may have been formed at great distances from the channel through which the vertical movement occurred.

6. The vertical spreading just mentioned may have been up or down, depending upon whether the solutions were flowing above or below an impervious or non-replaceable rock. (At the time of Emmon's examination, only ore bodies formed by downward replacement were exposed, but it is now known that some of the largest masses of ore were deposited from solutions working upward from the contacts.) The vertical spreading may in some cases have been concentrated along a fissure or a narrow jointed zone, the solutions ultimately spreading laterally along contacts considerably above or below that along which the lateral movement began.

7. Ores may or may not have been deposited in the various ore-solution channels just mentioned, depending upon the nature of the solutions and of the country rock, the rate of flow of the solutions, the temperature of the country rock, the pressure upon the solutions, and other factors. (It was the erroneous assumption that there must exist traceable connections of ore between the replacement deposits and their immediate source that made Emmons hesitate to accept the fissure theory.)

8. It is quite probable that many replacement ore bodies were formed along one or more contacts, each of which received its ore through the same vertical or inclined channel, and that these masses were separated from the channel and each other by barren stretches. It is not necessary, therefore, to seek a channel extending downward from each of the ore bodies.

9. It is not improbable that a portion of the ore in the replacement deposits may have originated as a result of magmatic emanations from the porphyry intrusions, but this source is believed to have been of decidedly minor importance.

A GEOLOGICAL STUDY OF THE ELISA MINE, SONORA, MEXICO.

MONTROSE L. LEE.

INTRODUCTION.

This study of the geology of the Elisa mine was made possible through the kindness of Dr. L. D. Ricketts, general manager of the Greene-Cananea Copper Co., which operates the property. Mr. J. M. Boutwell, consulting geologist, made valuable suggestions as to methods of study and Mr. N. L. Macdonald, mine foreman, was very courteous in assisting at the mine.

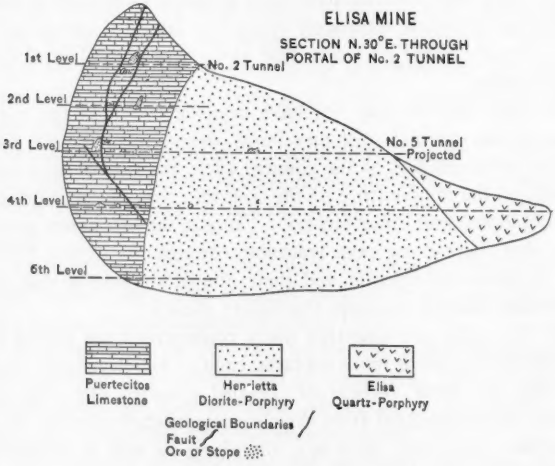

FIG. 40.

During the year 1907–08 as a part of a large general survey of the Greene-Cananea mines by Dr. S. F. Emmons and assistants, the geological section at the Elisa mine was studied and mapped

by Mr. L. C. Graton. The writer has had the benefit of these observations and has been much assisted by them. More detailed study has brought out some additional points which are considered to be sufficient to justify this paper.

Situation.

The town of Cananea in the northern part of the state of Sonora, Mexico, is about 38 miles southwest of Naco, Arizona,

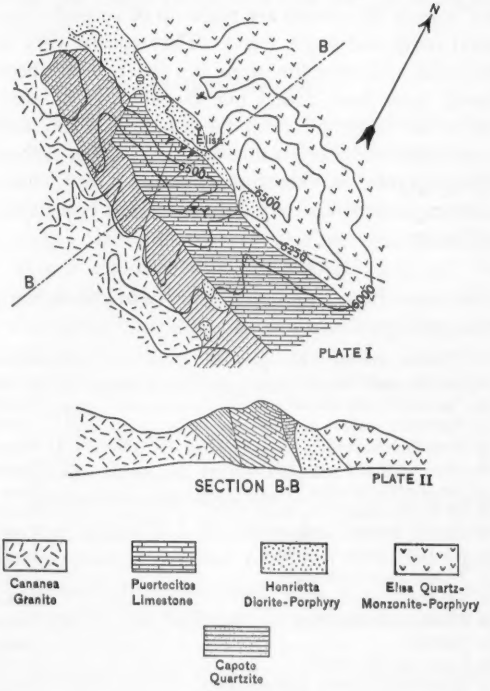

FIG. 41.

with which it is connected by a branch of the Southern Pacific Railroad. Naco lies on the international boundary. About three

miles northwest of Cananea at the head of a narrow gulch is the Elisa mine. The mine was formerly reached by a narrow-gauge railroad, but now it is connected by a tunnel with the Capote mine. The ore goes to the mill by underground haulage. The tunnel mouths all lie above the 6,000-foot contour so that the mine is situated a thousand feet higher than Cananea.

General Geology.

The Cananea Mountains are made up of several ridges having a general north and south trend. They consist very largely of igneous rocks with some limestone and quartzite of uncertain age. No fossils have been found but the age of the sediments is believed to be Cambrian from the lithological similarity to the Bolza quartzite and Abrigo limestone of Bisbee, Arizona. The underlying granite is, therefore, Precambrian. The eruptives have been considered Tertiary although direct proof fails with so few sediments.

ROCK DESCRIPTIONS.

Dr. Emmons from an extended survey of the region gives the following geological succession:

1. Cananea granite	Precambrian.
2. *Capote quartzite*	Cambrian.
3. *Puertecitos limestone*	Tertiary.
4. Mariquita diabase	Tertiary.
5. Huacalote rhyolite	Tertiary.
6. Mesa tuffs and agglomerates	Tertiary.
7. San Pedro andesite	Tertiary.
8. El Torre syenite	Tertiary.
9. Elenita syenite-porphyry	Tertiary.
10. *Henrietta diorite-porphyry*	Tertiary.
11. Tinaja granite-porphyry	Tertiary.
12. Cuitaca granodiorite	Tertiary.
13. *Elisa quartz-porphyry*	Tertiary.
14. Gabbro	Tertiary.
15. Later diabase dikes	Tertiary.
16. Quaternary gravels and alluvium	Tertiary.

Only the four italicized above occur at the Elisa mine and will be described. Their distribution in this vicinity is shown on Plate I., Fig. 41.

Capote Quartzite.

As this formation does not occur in the mine workings and probably has very little to do with the deposition of the ore, only one sample near the contact with the limestone was taken. The thin section shows a fairly pure fine-grained quartzite. A few grains of zircon and a little sericite are to be seen. The cement is chalcedony stained with iron oxide. The quartz grains are well rounded and fairly uniform in size varying from 0.05 to 0.1 mm. in diameter.

Puertecitos Limestone.

The Elisa ore deposits occur in this limestone which lies conformably upon the Capote quartzite. No fossils have been found. Much has been altered to garnet and diopside with the addition of sulphides, thus obscuring its original character in the mine workings. However, where bedding was noted underground it agreed with that shown on Plate II, Fig. 41. On the surface at the top of the ridge the bedding is more apparent, due partly to weathering and partly to the absence of metamorphism. Here the beds vary in thickness from one half to three feet and are noticeable because weathering has made the silicious layers stand out in relief.

These cherty layers, the similar bedding and the general low magnesia lead Dr. Emmons, in the absence of fossil remains, to assign this formation to the same age as the Abrigo limestone of Bisbee, Arizona which Mr. Ransome determined as Cambrian. The limestone which is quarried for flux runs about 5 per cent. insolubles and about 1 per cent. magnesia. Locally the magnesia and other impurities run higher as shown later by an analysis of mine rock.

The garnet rock is light brown with a greenish tinge and a greasy luster. Weathering produces limonite and silica which resemble gossan. Less intense alteration has produced marble. When fresh the rock is tough and dense.

Henrietta Diorite-Porphyry.

This is the name given by Dr. Emmons to the formation shown on Figs. 40 and 41.

On page 325 of ECONOMIC GEOLOGY, June, 1910, the following description appears:

"This is the most extensive and economically the most important rock of the region, for its eruption has produced the greatest contact metamorphism and has been followed by the most extensive mineralization.

"As a formation or rock unit it is more variable than any of the others and may include more than one individual species. In texture it varies from a medium-grained granitic type through porphyritic to a dense, dark, almost glassy rock in which no phenocrysts are visible, and which resembles an indurated argillite."

Page 327:

"While there is abundant evidence that this rock is intrusive there are places in the fine-grained rock where there is a decided tendency toward bedding. This is especially definite along the railroad, a half mile east of Puertecitos, where the apparent bedding dips northeast at about the same angle with the sediments, and specimens examined under the microscope look tufaceous, thus suggesting that in part it may have been the result of explosive action."

Page 351:

"In kaolinized and bleached condition of the country rock, it is at times impossible to determine whether a given specimen is diorite or tuff, especially as the former often has a finely brecciated or clastic structure."

The writer's observations were confined to the Elisa mine and vicinity where he found this formation entirely tufaceous with no diorite-porphyry. In the mine this rock varies in color from light to dark gray with a greenish tinge due to epidotization. Near the surface it is often bleached to nearly white but on the surface it is usually iron stained. The grain is uniformly so fine that at no place could phenocrysts be seen with a hand lens. In an intrusive 600 feet or more thick this is unusual. Bedding was not noted.

The microscope shows fine angular pieces of quartz with a

few grains of feldspar in an altered groundmass of epidote and sericite with a very little chlorite. The few feldspar grains are either plagioclase or microcline. The texture of the formation as a whole is remarkably uniform—the grains averaging less than 0.1 mm. in diameter. A little pyrite and some secondary quartz occurs. The alteration products would indicate the action of magmatic rather than meteoric waters. Some of the slides show fine splinter-shaped grains indicating sub-aerial and not sub-aqueous deposition.

The fineness and uniformity of grain lead, making it probable that the volcanic source of this tuff was at a considerable distance from the place where the material was deposited, renders it extremely improbable that the formation is a flow-breccia.

An analysis of the tuff, made by Mr. F. G. Hawley is given below. From this the mineral composition of the tuff has been calculated.

	Per Cent.
Silica	64.7
Alumina	14.3
Ferrous oxide	3.9
Ferric oxide	nil
Lime	3.9
Magnesia	2.7
Manganese oxide	0.4
Pyrite	3.8
Zinc	0.3
Soda	1.9
Potash	3.1
Water	not det.
Total	99.0

	Per Cent.
Quartz	26.6
Orthoclase molecule	19.4
Albite molecule	17.2
Anorthite molecule	20.6
Hornblende	14.6
Kaolin	1.6
Total	100.0

The large amount of free quartz indicates that the tuff is a dacite tuff rather than an andesitic tuff.

A bedded formation called "mesa-tuff" nearly surrounds the Cananea mountains, but the Elisa tuff, probably is another formation and is not to be confused with it.

From the data presented above it appears that the so-called Henrietta diorite-porphyry, instead of being an intrusive diorite-porphyry which might have produced the Elisa ore bodies and garnet zones, is entirely fragmental and of a composition such that it could not have been derived from a diorite.

Elisa Quartz-Monzonite-Porphyry.

The distribution of this eruptive and its relation to the limestone in the vicinity of Elisa is shown on Figs. 40 and 41. In the field this rock is easily recognized by the large rounded quartz phenocrysts in a finely granular groundmass principally of orthoclase. The fresh rock is greenish gray, but when exposed to weathering the groundmass is bleached by kaolinization and silicification.

Under the microscope the quartz phenocrysts show much corrosion and many embayments. In addition to the kaolinite of the small orthoclase crystals in the groundmass there is considerable secondary quartz, especially in minute fissures where pyrite also occurs. From the occurrence of pyrite in this intrusive, which is said to be cupriferous, and from studying the rock elsewhere in the district Dr. Emmons attributes part, at least, of the mineralization to it.

THE FAULT SYSTEMS.

The greatest fault in the district cuts the limestone of the Elisa mine in a nearly east and west direction and takes its name from the mine. The dip of the Elisa fault is steep but variable as shown by the section on Fig. 40. Cutting as it does a much metamorphosed, nearly massive limestone with no distinctive beds the amount of movement is difficult to determine. Dr. Emmons considers the displacement as possibly less than a thousand feet and as later than the mineralization of the limestone. Confirming this latter statement I found in the gouge between the walls of the fault, ore showing slickensides.

A lesser system of faults strikes nearly north and south and from the sharp way in which it cuts the ore bodies it is undoubtedly of later origin. Many of the drifts follow the Elisa fault and where the second or lesser system of fissures can be traced on both walls of the great fault small lateral movement was observed. That is to say, the north wall of the Elisa fault has moved 15 or 20 feet west with respect to the south wall. This makes the Elisa fault subsequent to the north and south fissures which latter are older than the ore as noted above. How much vertical movement is involved could not be ascertained and no mention would be made of such a small lateral movement were it not for the light which it throws upon the relative ages of the mineralization of the limestone and the large fault.

Ore deposits frequently owe their origin to solutions moving along fault planes and a realization of this fact combined with a knowledge of the fault systems involved may be of much assistance in directing exploratory work. It is at least of some importance to know that these two fault systems are not connected with the formation of the ore. The main drifts follow the Elisa fault not because of its genetic relation to the ore but because it affords an excellent wall to break to in mining and also is fairly central with regard to the ore bodies.

CONTACT METAMORPHISM.

The garnet zones, as developed by the underground workings, lie near the Elisa fault favoring the north side. In these irregular zones occurs the copper, mostly as the mineral chalcopyrite. Associated minerals are garnet, diopside, quartz, epidote, calcite, pyrite, chalcopyrite, blende and minute amounts of galena and tetrahedrite.

Garnet is by far the most abundant and makes a light brown rock with a greenish tinge and a greasy appearance. Weathering results in the formation of limonite and silica resembling gossan. From the analysis below by Mr. F. G. Hawley, the following mineral composition has been calculated.

FIG. 42. Ordinary light—transmitted. × 80. Photomicrograph of chalcopyrite veinlet through garnet. Garnet shows zonal structure. Black is chalcopyrite, gray is garnet and white is void.

	Per Cent.
Silica	35.5
Alumina	5.3
Ferric oxide	21.3
Ferrous oxide	0.2
Lime	32.5
Magnesia	2.8
Manganese oxide	0.7
Carbon dioxide	2.4
Sulphur	0.15
Total	100.85

	Per Cent.
Calcite	5.5
Spessartite	1.6
Pyrope	5.2

Grossularite	16.2
Andradite	67.7
Diopside	3.7
Quartz	0.1
Total	100.0

The rock therefore shows about four times as much of the andradite molecule as the grossularite molecule.

The unaltered limestone quarried for flux averages about 5 per cent. insolubles and less than one per cent. magnesia. It is readily seen that much ferric iron and silica must have been added to the fresh limestone to have produced garnet rock of the above composition. It might be argued that heat has formed the contact minerals by the recrystallization of very impure parts of the limestone without any addition of new material. If this were the case we should expect the garnet to follow the impure beds and not the others. The bedding, however, crosses the ore bodies and garnet masses. The distance of the garnet from any eruptive excludes the possibility of the metamorphic minerals having been formed from the absorption of limestone by a molten intrusive.

Contributions to a fairly pure limestone from an eruptive, recrystallization of an impure limestone, and the absorption of limestone by a molten magma are the three hypotheses usually advanced for the explanation of contact garnet zones. In this case the first theory, by contributions from an eruptive, seems the most acceptable. This theory supposes that the molten magma in cooling and crystallizing expels much water; at first in the ionized state when very hot, later as steam and finally as hot water. In any or all of these states water may carry in solution the materials—principally silica and ferric oxide in this case—required by the limestone to form contact minerals as garnet, diopside, etc.

Accepting this genesis the determination of the eruption which has produced the metamorphism is more difficult. In speaking of the Elisa mine on page 338 of ECONOMIC GEOLOGY, June, 1910, Dr. Emmons says:

"The diorite-porphyry, which adjoins the limestone on the northeast, appears to have been the main cause of the contact-metamorphism, but the quartz-porphyry which immediately adjoins it, at a distance of a few hundred feet from the contact, may also have exerted some action."

The writer's study of this so-called diorite-porphyry has convinced him that it is not intrusive but finely fragmental and as such could not have produced contact metamorphism. Hence the active intrusive must be sought elsewhere.

To the south underlying the Capote quartzite and the Puertecitos limestone is the Cananea granite, but this rock had consolidated and cooled long before the deposition of the limestone, and therefore was not active in the formation of the garnet zones.

To the north is the Elisa quartz-monzonite-porphyry which Dr. Emmons mentions as a possible source of mineralization. Intervening between it and the limestone is 600 feet and more of fragmental rock (tuff) through which solutions from the quartz-porphyry must have passed to reach the limestone. Much sericite and epidote in the tuff point to the action of hot magmatic waters. The occurrence of these minerals may, therefore, be considered as favorable to the quartz-porphyry as a source of the materials added to the limestone.

Near the surface, as noted above, the distance between the quartz-porphyry and limestone is great. If we imagine quartz-porphyry beneath the limestone producing hot rising solutions along cracks and fissures, we have a simpler explanation of the contact effects. Sustaining this supposition of an underlying intrusive, the writer found rounded quartz-porphyry pebbles carried to the surface in a fault exposed just above the first level. A thin section of one of these pebbles identified it as typical Elisa quartz-monzonite-porphyry. This fault lies about 75 feet east of the portal of Tunnel No. 1 and strikes N. 70° E. and dips 65° S. E.

Diopside, the next mineral in importance, has the formula $CaSiO_3 \cdot MgSiO_3$ and contains 18.5 per cent. magnesia. Some thin sections show much more diopside than others and we may think of it owing its origin either to contributions of magnesia

from an intrusive or to the original limestone locally rich in magnesia. Supporting the latter view is an analysis by Mr. F. G. Hawley of a piece of apparently fresh limestone from the sixth level in which the magnesia is especially high.

	Per Cent.
Silica	8.2
Alumina	1.7
Ferrous oxide	1.5
Ferric oxide	2.9
Lime	33.8
Magnesia	10.8
Manganese oxide	0.7
Pyrite	0.5
Carbon dioxide	not det.

Later than the garnet and diopside is pyrite either in masses or in minute cracks cutting the silicates. When surrounded by the other sulphides as in the ore, pyrite often exhibits well formed

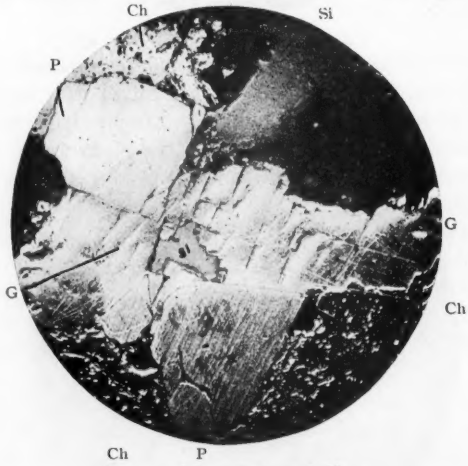

FIG. 43. Microphotograph No. 1.

faces as in the microphotographs 1 and 2 which make the chalcopyrite the younger. In the microphotograph 3 the pyrite has been brecciated and the grains somewhat rounded. Tetrahedrite

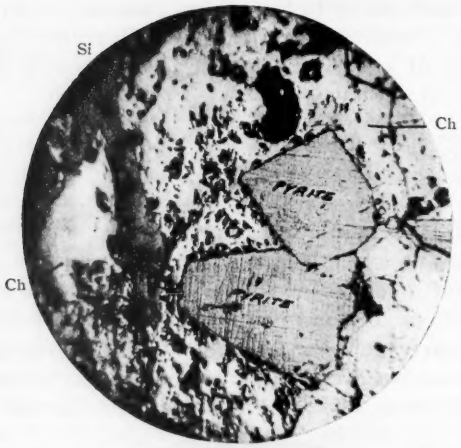

FIG. 44. Microphotograph No. 2.

FIG. 45. Microphotograph No. 3.

is moulded about these grains proving its introduction to be later than the brecciation.

Small amounts of zinc blende are seen in some of the workings. The only thin section containing this mineral, seemed to show that the blende and pyrite were of the same age.

Quartz in little veinlets cuts all the other minerals and undoubtedly was the last formed. Tiny fissures filled with pyrite have been reopened and filled with quartz.

Much of the limestone has been changed to marble but as such it is not intimately associated with the ore.

The paragenesis of the minerals is as follows:

1. Garnet and diopside.
2. Pyrite (and blende?).
3. Chalcopyrite, galena and tetrahedrite.
4. Quartz.

ORE DEPOSITS.

At Elisa the copper is almost entirely in the mineral chalcopyrite associated with pyrite, garnet, diopside and a little quartz. The only secondary minerals found in any quantity are above the first level where chalcocite and the carbonates, malachite and azurite, are seen along with chalcopyrite. Secondary enrichment undoubtedly took place near the surface where the ores, now exhausted, were of higher grade than those mined at present in the lower levels. Below the first level no enrichment is believed to have occurred. This may be due to the tight tough nature of the garnet rock which has successfully resisted fracturing and thus prevented the downward percolation of copper-bearing solutions.

This conclusion, if correct, has an important practical bearing on the depth to which ore may extend and the copper content which may be expected. The ore in the lower levels being primary—*i. e.,* there having been no enrichment nor leaching since deposition—there should be no change in tenor and the ore should continue in depth as far as the limestone has developed into a garnet zone.

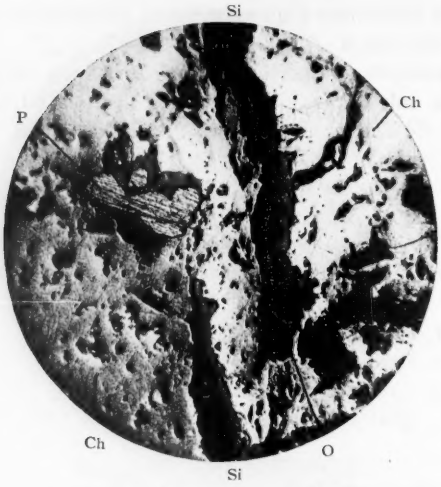

FIG. 46. Microphotograph No. 4.

FIG. 47. Microphotograph showing chalcopyrite (light) moulded about garnet (dark).

The ore makes irregularly but in rudely lenticular masses which have their long axes more or less parallel to the Elisa fault but as stated before no genetic connection between the two was observed. More ore is found north than south of the fault. Much garnet and less diopside come with the copper.

The genesis of the ore and accompanying silicates has already been given under the heading of Contact Metamorphism.

THE GEOLOGY OF THE ST. HELENS MINING DISTRICT OF WASHINGTON.

CARL ZAPFFE.

INTRODUCTION.

The St. Helens mining district of Washington embraces parts of T. 9 and 10 N., R. 5 and 6 E., Skamania Co., and T. 11 N., R. 5 E., Lewis Co., a roughly estimated area of about one hundred square miles in the southern portion of the Cascade Mountains, only about ten miles north of the Oregon-Washington state boundary line, the Columbia River, and about fifty miles east of the Portland-Tacoma branch of the Northern Pacific Railway Company. It is also a part of the Mt. Rainier national forest reserve.

The district derives its name from Mount St. Helens, an extinct volcano, the symmetrically rounded sugar-loaf-like cone of which is in T. 8 and 9 N., R. 5 E., at the southern edge of the district. This snow-capped peak, which towers far above the surrounding country, is the fourth highest one in the state, reaching an altitude of 9,750 feet, and was built up independently of the general uplift of the Cascade Range.

There are no mines in the district but prospecting for copper, gold and silver has been carried on irregularly for about fifteen years. During the summer of 1911 the writer had the opportunity to visit about 250 mineral claims in various parts of this district. Seventy-five tunnels, aggregating 11,000 feet in length, were examined.

The United States Geological Survey has published one bulletin,[1] two annual reports,[2] one professional paper,[3] and four

[1] I. C. Russell, Bulletin No. 108, 1893.

[2] I. C. Russell, 20th Annual Report, 1898–1899; J. E. Spurr, 22d Annual Report, 1901–1902, 2d pt.

[3] Smith and Willis, Professional Paper No. 109, 1903.

folios,[1] and the Washington State Geological Survey has published one bulletin[2] pertaining to Cascade Range areas but the areas described are all northern ones, and further, excepting Spurr's report on the Monte Cristo area and the Tacoma folio (which is entirely about Pleistocene deposits) the areas are all in the eastern Cascades. Nothing apparently having ever been published regarding the geological conditions in the southwestern Cascades of Washington, a summary of the writer's observation in the St. Helens District is appropriate.

After traveling fifty miles due east of Castle Rock, a town on the Northern Pacific Railway, the foothills were crossed and the first claims to be examined were reached. The trail used from here on followed up Green River, and in the investigation the river was followed as a base line, first eastward and then southeastward up to near its source on the east side of the base of Mt. St. Helens, an additional distance of about twelve miles, from whence the return to Castle Rock was by a more southerly but parallel route, thereby having described an ovate course of about 125 miles, but the loop at the east end where the examinations were made was only about eight miles wide. The nature of the investigation made it obligatory to leave many interesting geological matters unexamined.

PHYSIOGRAPHY AND TOPOGRAPHY.

The district is mountainous. The mountains are rugged, have precipitous slopes and terminate above in small flats or in high serrated ridges and narrow spurs with spires and minarets of rock. The highest elevation reached on a ridge was 5,400 feet, and probably no ridge in this area was materially higher, but there are a few projecting spires or knobs which probably do not exceed this figure by more than one hundred feet. As one looks northeastwardly from this high elevation and takes a panoramic view of the Cascade Range beyond the district in question, he is

[1] Tacoma folio No. 54, 1899; Ellensburg folio No. 86, 1903; Mt. Stuart folio No. 106, 1904; Snoqualmie folio No. 139, 1906.

[2] Blewett Mining District, Bulletin No. 6, 1911.

impressed with the persistent relatively even altitude of all the ridges which he may be able to see, truly monotonous compared with the beautiful views below.

Aside from the plateau-like summit the topography is everywhere youthful, but rapidly maturing. Rock slides or avalanches are of frequent occurrence and many tons of rock are yearly transported from the tops to the bases of the slopes. The rock gouges into the mountain side and leaves behind smooth and polished grooves and sloping lanes which generally can be crossed only with hazard. Many of these have become stream beds, and the water slides down the smooth rock in one long sheet. The name Devil's Slide Creek given by an early prospector to one such stream is a most fitting and correctly descriptive name.

High on the ridges are amphitheaters, or cirques, which once held glaciers, and there were still numerous névés during the warm month of August. At these altitudes are also emerald glacial lakes. Glacial striæ were frequently observed, and there seems to have been considerable glacial erosion in the past. The snarled and stunted growths of timber at the high altitudes suggest the vicissitudes caused by ice, snow and disrupted rock.

The precipitation is heavy and a large quantity of water is annually carried to the Pacific Ocean. The drainage of the district is westward through Toutle River into Cowlitz River. Toutle River is formed by the three forks known as Green River (or North Fork), Middle Fork, and South Fork of Toutle River. Green River rises at the northeast side of the base of Mt. St. Helens, the Middle Fork rises on the west side of the cone, and the South Fork at the south side of the base. In courses parallel to Toutle River and its forks are Lewis River to the south and Cowlitz River to the north of the area visited, but the latter river turns abruptly where it reaches the Northern Pacific Railway and then flows southward into Columbia River.

Green River flows in an east-west valley varying from one quarter to one half mile in width. In places there are suggestions of old terraces. The river has a steep gradient, a few narrow and shallow canyons, and, in the upper portion of its

course, two waterfalls of about eighteen and thirty feet in height. The river rises in the mountain heights and its waters are cold and clear, and have that characteristic mountain-green color which gives it its name. In contrast to this, the water of the middle fork of the Toutle rises on the side of the cone of Mt. St. Helens and is filled with a fine gray sediment which makes this fork look like a stream of milk. Green River is fed by many cascading streams, most of which flow down the north slope of the adjacent mountain ridges. The river bed is full of boulders, debris and accumulations of pumice.

LITHOLOGY.

This district is conspicuous for its lack of clastics. The varieties of rocks noted were named as follows in the field, diorite, aplite, basalt, dacitic andesite, andesite porphyry, andesite tuff, pumice and volcanic ash.

The diorite, the predominant rock of the district, is a fine to medium-grained granitoid rock prevailingly of light color though in places almost dark green. Plagioclase feldspars and hornblende are always easily discernible with the naked eye, and sometimes also biotite, quartz, tourmaline and various sulphide minerals. Except along certain few lines of disturbances, the diorite was not seen to be affected by metamorphism other than mechanical disintegration and the minerals were, therefore, fresh, and the rock tough. Tourmaline is frequently a conspicuous constituent, so much so that one ridge is known as Black Mountain ridge because of the frequent occurrence of the black tourmaline. There are in places some beautiful radial aggregates of black tourmaline, sometimes accompanied by iridescent tarnished cupriferous pyrite. Pyrite is also locally an important constituent. Even in the field it was quite evident that the diorite mass presented several facies, and a microscopic examination later showed that it varied from a quartz monzonite to a quartz-free diorite. Due to its jointing and resistance to weathering, it forms high peaks and serrated ridges, and its purple, weather-stained color made it recognizable at great distances.

The aplite is a flesh-colored, very fine-grained rock consisting of quartz and feldspar. Excepting for its color and its occurrence in small dikes or stringers, especially along joint planes, there was nothing conspicuous or important to be noted about it.

The basalt is a tough, very fine grained, black colored rock with a green tinge. Rarely were flow lines noted. The basalt was not exposed very much. It was not examined under the microscope. The absence of scoriaceous and vesicular textures was striking. Although the basalt was jointed, yet it lacked the usual columnar structure which one generally associates with the western basalts. The effects of weathering were practically *nil*. Together with its massiveness and its position, it is quite likely that this rock has been indurated by an intrusive whereby its usual characteristic development has been prevented. An outcrop of a platy, weather-stained, black, porphyritic basalt was noted along the road about twenty-five miles east of Castle Rock.

Andesitic lavas occur abundantly. The flows closely associated with the basalt described are dacitic. They are dense, tough (devitrified possibly), and porphyritic. The phenocrysts are cherty dull quartz, feldspar and pyroxenes. In one locality, where observed over a comparatively wide area, the groundmass had a purple tone, whereas in another locality, where presumably the same formation existed, the groundmass was olive green to bright green. Other andesite, occurring in thin beds in the volcanic tuff (to be described) is green, gray and red in color, more feldspathic and glassy, and more porous than the dacitic andesite.

The andesite porphyry is a porphyritic rock of light green or lavender color. The feldspar phenocrysts, easily seen and predominant, make this rock, when partly altered, most conspicuous. A recent microscopic examination showed that this rock also contains hypersthene phenocrysts. This porphyry is the common dike rock.

The andesite tuff formation presents an interesting variety for study. Portions vary from gray, green and red shades to black, from soft to hard, from volcanic flow breccias to volcanic tuffs.

At one place, near the bottom of the formation, is a flow breccia containing fragments of diorite, basalt and dacite, and small segregations of epidote and magnetite crystals along parting planes and in vuggs. At higher horizons the diorite fragments are lacking, and thin red and green andesite flows occur interbedded. At another place is a conglomeratic phase, apparently of lacustrine origin, with a pseudo-cross-stratification, and with boulders several inches in diameter of chert, pumice, andesite porphyry and some shaly pebbles. Nearby is a large, white, scoriaceous bedded mass, like a partly powdered slag, also masses of black flint and light gray, banded chert. The chert is distinctly bedded in layers about one inch in thickness. It is minutely fissured, and contains numerous thin veinlets of quartz. The conglomerate, the chert, the flint and the scoriaceous mass occupy a large depression in the hill side above the river bottom, and further investigation might perhaps prove them a separate formation.

Volcanic ash and pumice form a mantle over most of the district. In places the little pumice pebbles have accumulated and walking is made most difficult and tiresome. Volcanic ash and pumice were probably deposited interruptedly. They are gray, purple, red and black. The pumice of darker colors is most abundant close to the cone of Mt. St. Helens.

STRUCTURE.

The hurried and limited examination of the areal distribution of the different rock formations permits but little to be said of the geological structure. The diorite mass probably is a batholith, now exposed by erosion, contemporaneous in origin with an upwarping of the Cascade Range. The nature of the rocks that once covered it was not determined and perhaps cannot be determined definitely by anything in this small area. No dioritic dikes or apophyses were seen in the superadjacent basalt or dacite flows to indicate by such evidence that the diorite intruded them, but both flows show so little characteristic weathering and are so very dense and tough that it is not at all unlikely that they were heated and devitrified by this large granitic mass, thus

suggesting an intrusive relationship. The batholith is intruded by small aplite dikes, none of those seen exceeding six inches in width, also by andesite porphyry dikes as wide as ten feet.

Basalt flows were the rocks seen nearest the batholith, but not in contact, and they were dipping gently away from it. It is not known how extensive this formation is, but it did not seem to be thick. Basalt occurs fifty miles west at Castle Rock station, and at intervening points, as previously referred to, but whether these rocks are of the same age cannot now be stated. Mention is made of this because north of Castle Rock along the Northern Pacific Railway basalt overlies limestone. The basalt is also intruded by the andesite porphyry dikes, but not by the aplite, one of the former probably exceeding fifty feet in width.

The basalt seems to be interbedded with dacite andesite flows. There was found almost a gradual change from the one to the other where an observation was possible.

Overlying the basalt and the dacitic flows is the volcanic tuff formation dipping generally southwest at variable angles. Contacts between the basalt and the tuff were observed, and in at least two different places the lower portion of the tuff formation was seen to be a volcanic breccia containing diorite, basalt and dacitic boulders. No intrusives were noted in the tuff. This formation was seen at some very high elevations as well as low ones, and suggests that rock character was not the controlling factor of the heights, but instead differential uplift.

Overlying all these formations are patches of pumice and ash ejected from the volcanic cone of Mt. St. Helens.

The age of the initial Cascade uplift has been placed by geologists of the United States Geological Survey as Tertiary,[1] and it seems that at least parts of the Range, if not all of it, have suffered a second large uplifting probably as late as Pliocene. The range is, therefore, very young, but the climate has been favorable for rapid erosion and large portions of the rocks have been removed. The formations outlined herein are west of the main divide and therefore probably represent the more recent rocks. It is not likely that the dioritic batholith

[1] Smith & Willis, Professional Paper No. 109, 1903, U. S. G. S.

represents the older or original mountain massif, consequently but little deformation has affected the formations described and the structure of the St. Helens district can be said to be gently inclined volcanic strata dipping westward from the diorite mass, and concealed further west by the younger formations of the Pacific coast, including the anderitic lavas of the extinct volcano Mt. St. Helens.

The prominent ridges trend nearly east and west, at right angles to the major uplift of the range, and were undoubtedly determined by local warping and faulting. The warping is suggested by the dips of the joint planes.

Faults appear to be notably lacking. One large east-west fault parallels part of the course of Green River for a distance of several miles, and it is likely that its length may be over five miles. It is entirely in the diorite, and its course can be followed by a bold cliff and a zone of close jointing, probably resulting from the overhanging side dropping. Some smaller faults were noted in all the formations, and along some of the andesite porphyry dikes, but no marked displacements seemed to accompany them.

Zones of shearing and of brecciation were frequently observed in the diorite, but these are also of small magnitude.

Parting along bedding was noted in the volcanic tuffs, especially where they are locally tilted.

Schistosity is nowhere developed, but jointing is most conspicuous, especially in the diorite. The joints strike in all directions but the major joints prevailingly strike in a general NW.-SE. direction, and along Green River they prevailingly dip steeply toward the river, indicating a preexisting syncline which now forms the basin of that river. Jointing largely determines the course of the river through this basin. The flat sets of joints enable the rapid sliding off of rock masses from the hill slopes, and also govern the formation of cascades or slides.

METAMORPHISM.

The metamorphism was almost entirely katamorphic. Snow, frost, ice, heat, vegetation and water have accomplished great

destruction, and the jointed condition of the rocks, and to some extent faulting and brecciation, have assisted materially.

The chief process of katamorphism is the mechanical disintegration of the rock masses. The masses have been disrupted continuously, the fragments and boulders have been dislodged freely, the debris has been carried down the mountain sides and valleys, and thus the present topography has been mainly carved.

Chemical decomposition has not been able to keep pace with mechanical disintegration and the rocks show only surficial stains, excepting along some of the fracture lines, and considering the abundance of the latter and the opportunities thereby offered, the chemical decomposition can truly be said to be extremely slight. There is, therefore, unfortunately for commercial considerations, no zone of weathering, within which oxidation, hydration, carbonation and sulphidation are usually active. The limited alterations seen along lines of fracture suggest the mere roots of such a zone. Further, the alterations along joint planes, faults, shear zones or zones of brecciation are generally only a few inches wide, rarely as much as two feet, and are localized where these fracture lines cross water courses. The most advanced alteration is always at the water course, and the degree of alteration decreases rapidly as the distance from the course increases. Even under the most favorable conditions for weathering the rocks are rarely altered to kaolin excepting to an extremely small extent. Along faults, alone, as seen in tunnels, the greatest quantity of kaolin was observed. This, no doubt, was largely fault clay formed by attrition.

The effects of weathering, as stated above, along lines of disturbance, occur only in the diorite and some of the andesite porphyry dikes. Other porphyry dikes and the tuff formation were apparently only bleached, whereas the basalt and dacite suffered only surficial stains.

Anamorphism played an insignificant rôle. Excepting for the possible heating and the questionable devitrification of the basalt formation by the intrusive diorite batholith, no other intrusives had any noticeable thermal effect on the rock intruded by them.

The shear zones referred to are but small faults in which the movement has probably been mainly lateral and also not sufficient to completely sever the mass.

ECONOMIC GEOLOGY.

Iron has been prospected for because of the presence of magnetite and specularite, both of which minerals exist sporadically in the diorite (magnetite crystals in clusters were also seen in the tuff formation), but apparently only a small amount of labor soon convinced the prospector of the uselessness of his task.

Considerable prospecting has been done for copper, gold, and silver, but today the district has all the indications of a field full of disappointments. Most of the prospecting was done in the diorite, a rock in which it is not unusual to find both disseminated and magmatic segregations of pyrite, chalcopyrite, arsenopyrite, galena and sphalerite.

Results of pneumatolytic action have been misinterpreted. When the diorite cooled and contracted it fractured, and gases and fluids under pressure rose in these fractures toward the surface and solidified during their escape, forming discontinuous veinlets or bands here and there, an inch or so wide, generally quite tourmalinic, and also containing a little frozen and comb quartz, some galena, sphalerite, specularite, chalcopyrite, pyrite, and arsenopyrite. Shearing or brecciation along these veinlets or bands has enabled weathering to take place more easily, and on these as well as along faults, joint planes, and other shear and brecciation zones much prospecting has been done. Clay and secondary pyrite have also been developed along fault and shearing planes and to this have been added the ordinary products developed by the weathering of a diorite. In such manner were formed those small original segregations of the above named minerals which lured the prospector.

Nowhere in the diorite in this district were metallic minerals seen in sufficient quantities to enable extraction profitably. Abundant arsenopyrite accompanies the sulphide minerals, and gold and silver values are either wanting entirely or extremely low.

The rapid disintegration of the rocks prevented secondary enrichment, the all important process for making valuable any copper deposits of this character. Nowhere was a gossan noted at the surface, and nowhere is the country rock widely decomposed. It is noteworthy that no chalcocite or bornite were observed.

Only one fissure vein was seen. This is about eight feet wide, but apparently not longer than one half mile, and its degree of mineralization was low. The district lacked projecting veins, resulting from differential erosion, and float quartz was nowhere noticed.

No auriferous gravels were found, and the mineralization which in other districts is often found near intrusive dikes, is practically absent.

THE ORIGIN OF THE SILVER-LEAD DEPOSITS OF EAST KOOTENAY, BRITISH COLUMBIA.

S. J. SCHOFIELD.

INTRODUCTION.

East Kootenay District of British Columbia, for the last decade, has been the largest lead-producing section of Canada. It occupies the southeastern portion of British Columbia and adjoins the northwestern part of Montana and the northern part of Idaho. The purpose of this paper is to discuss the origin of the silver-lead ores of East Kootenay and compare them with the similar deposits in Idaho. The field-work, on which this article is based, was done in connection with the geological mapping of East Kootenay for the Geological Survey of Canada.

GENERAL GEOLOGY.

The silver-lead deposits of East Kootenay occur in the Purcell range[1] which is made up almost entirely of sedimentary rocks of pre-Cambrian and possibly Cambrian age, called by Daly[2] the Purcell Series. This series consists of a great thickness of argillaceous quartzites, purer quartzites and argillites, with very subordinate amounts of limestone, folded into numerous northerly striking anticlines and synclines. These structures are truncated by normal faults which strike in a northeasterly direction. Intruded into the Purcell Series are several small cross-cutting bodies of granite and granite porphyry. The ore-bearing formation, the Aldridge quartzite, is the oldest known member of the Purcell Series and consists of a series of thick- and thin-bedded argillaceous quartzites (locally called slates). They are dark gray on fresh fracture and weather to a rusty brown color, which

[1] *Geog. Jour.*, Vol. 27, 1906, p. 588.
[2] R. A. Daly: Summary Report Geol. Surv. Can., 1904, pp. 91*A*–100*A*.

aids in identifying the formation in the field. An examination of the positions of the ore deposits shows that they are restricted

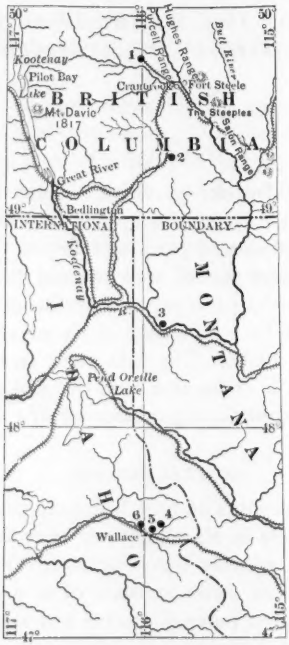

FIG. 48. Map showing relations of districts under discussion.

to the upper members of the above mentioned formation where the thick-bedded and purer quartzite strata are in greater abundance.

ORE DEPOSITS.

Sullivan Mine.—The deposit of the Sullivan Mine as indicated on the accompanying cut, is situated about 20 miles northwest of Cranbrook, B. C.

It produced during the year ending June 30, 1911, 34,065 tons

of crude ore containing 258,376 oz. of silver and 14,187,354 lbs. of lead. The gross value of this output was $635,223.

From 1894 to June 30, 1911, the total output was 126,175 tons containing 1,040,369 oz. of silver and 52,840,751 lbs. of lead with a total gross value of $2,566,449.[1]

The country rocks belong to the lower part of the Purcell Series and have a general N.–S. strike with dips varying from 20° to 80° to the east. The thick-bedded members of the ore-bearing series, the most favorable for replacement, appear, when examined microscopically, to be made up of angular interlocking grains of quartz 0.12 mm. in diameter with minor amounts of felspar and mica. The deposit strikes about N.–S. and dips to the east conformably with the enclosing quartzites, which on the 60-foot level dip 25° to the east and on the 100-foot level 75° in the same direction. In the upper part of the deposit close folding has increased the thickness of the ore.

The ore body is not a true fissure vein but is a replacement deposit conformable in dip and strike with the enclosing quartzites. The maximum stope width is 120 feet and the maximum stope length 525 feet.

The interior of each ore mass consists of an intimate mixture of zinc blende and galena with minor amounts of the iron sulphides, pyrite, pyrrhotite and jamesonite. Here and there through this mixture occur lenses of purer galena. The gangue, which is very small in amount, contains idiomorphic crystals of pink garnet, some diopside and actinolite with very subordinate amounts of calcite. This interior zone passes outwards into a fine-grained mixture of pyrite, pyrrhotite and small amounts of galena associated with crystals of colorless garnet, actinolite and biotite. The pyritic zone, in turn, with a gradual decrease in the amounts of sulphides, grades exteriorly into a cherty zone which is present only where the country rock is the heavy-bedded purer quartzite. When the more argillaceous slaty members are present, the pyritic zone passes into the normal country rock at that point. The cherty zone is free from gangue minerals and

[1] *Canadian Mining Journal*, Vol. 32, 1911, p. 707.

passes outwards into the normal quartzites which enclose the entire deposit. No garnet or diopside is present in the country rock and these minerals are entirely restricted to the area influenced by the ore solutions.

As mentioned, the ore deposit as a whole is a conformable replacement of fine-grained argillaceous quartzites by fine-grained galena, zinc blende and iron sulphides. Replacement is very

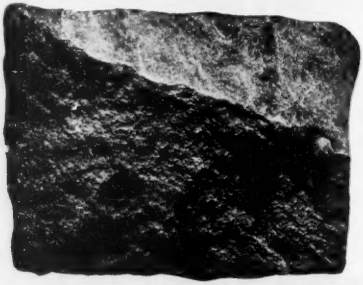

FIG. 49. Idiomorphic crystal of garnet embedded in fine-grained galena. Sullivan mine.

well shown in most parts of the deposit since alternate banding of ore and quartzite is seen near the periphery of the ore masses where the relative susceptibility to replacement of the laminæ of the quartzite is different. Joining these favorable bands are numerous interlacing veinlets of sulphides which, as shown in Fig. 51, represent an intermediate stage in the complete replacement of the quartzite. Examined microscopically, the sulphides appear to have entered between the quartz grains of the quartzite and then to have attacked the quartz itself. The sulphides, entering along the favorable laminæ replace the muscovite also, as shown in Fig. 52. Evidently muscovite has been formed previous to the introduction of the sulphides.

Paragenesis.—A paragenetic study of the ores shows that the gangue minerals are often in idiomorphic crystals (Fig. 49) and free from sulphides. Also, the small cracks in the gangue minerals are filled with a mixture of pyrite, pyrrhotite, zinc

blende and galena. From these facts, it is concluded that the gangue minerals have priority in formation. The relations of the gangue minerals to each other could not be ascertained as they were never seen in contact. There is a possibility that some of the sulphides were contemporaneous with the gangue minerals, for idiomorphic crystals of pyrite and arsenopyrite were observed embedded in the fine grained sulphides. This latter second gen-

FIG. 50. Pyritic zone. Numerous round dark patches are colorless crystals of garnet. Idiomorphic crystals of arsenopyrite are present but do not show in the photograph. The fine-grained matrix consists of an intimate mixture of pyrite, pyrrhotite and zinc blende.

eration of the sulphides is represented by a fine-grained intimate mixture of galena, zinc blende, pyrite, and pyrrhotite whose order of formation is so confused that they are believed to be contemporaneous. The sulpho-salt jamesonite is associated with small calcite veins which are later than the main ore bodies and is probably a secondary mineral.

The passage for the ore solution which formed the Sullivan deposit is believed to be the well-defined bedding planes of the quartzitic strata. From several such channels the solutions replaced the country rock within their sphere of influence.

St. Eugene Deposit. The St. Eugene mine which is located on the east side of lower Moyie lake near the town of Moyie, B. C., up till the close of last year has been the largest lead-producing property in Canada. It yielded during the year end-

FIG. 51. Polished surface showing methods of replacement.

ing June 30, 1911, 47,705 tons of crude ore and 7,708 tons of concentrates containing 204,044 oz. of silver and 9,012,152 lbs. of lead. The gross value of this output was $429,044. During the period from 1894 to June 30, 1911, the total output was 1,001,820 tons of crude ore and 187,833 tons of concentrates containing 5,259,477 oz. of silver and 225,076,673 lbs. of lead, having a total gross value of $10,394,520.[1]

The deposit of the St. Eugene mine occurs in a zone of fissuring which cuts across the axis of a northern plunging anticline composed of argillaceous quartzites belonging to the oldest member of the Purcell Series. In this zone, two fissures are the most important, both of which strike east and west with an average dip of 70° to the south. On the 1,000-foot level which

[1] *Canadian Mining Jour.*, Vol. 32, 1911, p. 707.

is 1,000 feet above the level of Moyie lake, these two fissures are 600 feet apart and converge downwards and to the west. Joining these two main fissures is an important system of connecting fissures at various distances apart which usually met the main fissures at a small angle. At this juncture or close to it, occurred most of the important ore bodies. Very little displacement has occurred along the veins as a whole.

The ore bodies are replacement deposits in the heavy-bedded purer quartzites and are restricted to the fractured area between the two main fissures. Where the fissure crosses the more argillaceous quartzites, it is usually filled with quartz containing small quantities of sulphides.

The ore consists mainly of coarse-grained galena with subor-

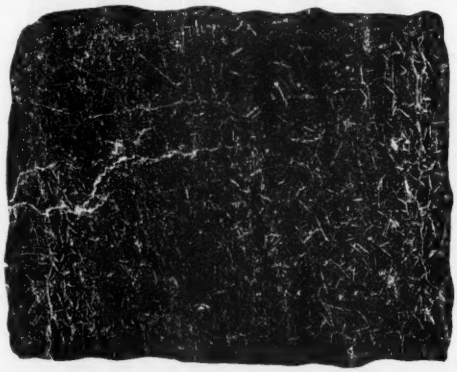

FIG. 52. The needle-like forms are pyrite pseudomorph after muscovite. Dark background is quartzite.

dinate amounts of zinc blende, pyrite, pyrrhotite, magnetite, and a little chalcopyrite. It is also reported that the sulphides—pyrite and pyrrhotite—were slightly more abundant near the periphery of the ore bodies. The gangue which is small in amount consists of pink garnet, actinolite, quartz and some calcite. The garnet, actinolite and quartz are more abundant in the transition zone of the ore and country rock, and at times the fissured quartzites

near the vein are heavily charged with these minerals. In addition the quartzites in certain localities show evidences of silicification although no true chert, as found in the Sullivan deposit, was identified in the St. Eugene.

A study of the paragenesis of the ores of the St. Eugene shows that magnetite was the first mineral deposited and was followed by the gangue minerals. The garnet, with approximating idio-

FIG. 53. Photomicrograph of St. Eugene gangue: black areas, crystals of magnetite; grayish black, garnet; fibrous mineral, actinolite, crossed nicols. × 16.

morphic outline, is penetrated by numerous needles of actinolite. The sulphides were deposited last and fill the cracks and interstices of the other minerals. The above relations are shown in Fig. 53.

GENESIS OF THE DEPOSITS.

The presence of the diagnostic minerals, garnet, diopside, actinolite, and muscovite, which are entirely restricted to the ore deposit and absent from the surrounding quartzites, suggests that the deposition of the ore took place in the deeper vein zone under conditions of temperature and pressure, comparable to those of contact metamorphic deposits. No igneous intrusion which

could supply solutions of this kind outcrops within several miles of these deposits. However, in the neighborhood of the Sullivan mine, small sills of gabbro older than the ore deposit are exposed and in the St. Eugene, a dyke of diorite cuts the vein. The areal study of the East Kootenay district revealed numerous cross-cutting bodies of granite and granite porphyry which are probably subordinate or "cupola" stocks of the West Kootenay granite batholith. In addition, the areas of sillimanite garnetiferous mica schist in East Kootenay are interpreted as argillaceous quartzites metamorphosed by an intrusion of granite not yet exposed by erosion. It is therefore concluded that the Purcell Series of East Kootenay, in part, rests upon an intrusive basement of granite which was the source of the ore solution, resulting in the formation of the Sullivan and St. Eugene ore masses.

The St. Eugene vein, described above, represents a fissure filled under conditions less extreme than those of the Sullivan, since garnets are less plentiful, galena is coarse-grained and more abundant and holds smaller quantities of zinc blende and pyrrhotite. In addition carbonates are more abundant.

COMPARISON WITH COEUR D'ALENES.

In comparing the deposits of East Kootenay with those of the Coeur d'Alenes, the genetic relationships become still more clear. In both regions, the deposits occur under similar geological conditions and as replacement deposits in fine-grained argillaceous and purer quartzites. The description of the various types will be given in an order corresponding to a decrease in conditions of temperature and pressure, starting with the most extreme, those formed under contact metamorphic conditions. A rather full description of the Granite or Success mine is given as in this deposit the relations to the intrusive is clearly shown. This deposit has been described by Ransome[1] in the following words:

> "The ore of the Granite Mine is exclusively confined to the tongue like mass of slate and quartzite which . . . extends almost entirely across

[1] F. L. Ransome: U. S. G. S. Prof. Paper 62, p. 184.

the large intrusive body of monzonite north of Gem. There is no vein, the ore occurring in masses of irregular form and various sizes, which are clearly for the most part replacements of the quartzites in places where the latter has been most thoroughly fissured. The ore masses in so far as they exhibit any regularity at all are suggestive of lenses standing on edge, the shortest diameter of nearly every mass being approximately horizontal. In the upper workings, the ore consisted chiefly of galena carrying about three quarters of an ounce of silver to each unit of lead. It is said that almost all the ore bodies contained an increasing proportion of sphalerite in their outer portions and that where the ore finally graded into the country rock the principal constituent was pyrite. . . . The ore usually contains a little chalcopyrite and probably pyrrhotite, although none of the specimens collected show the latter mineral. There is very little gangue other than the mineralized quartzite. In places a little quartz is crystallized with the galena but siderite seems to be entirely absent. The ore is strictly confined to the sedimentary rock which probably belongs to the Prichard formation although the quartzitic character shows that it is near the top of the formation. . . . The quartzite all shows some metamorphism due to the intrusion of the monzonite. . . . In consequence of it, the rock usually has a green color, due to the development of minute grains of pyroxene or in a few places a pink tint where garnet in microscopic crystals is the principal contact metamorphic mineral. The microscope shows that the quartzite is completely recrystallized to an aggregate of interlocking quartz grains which enclose variable proportions of the pale green monoclinic pyroxene, green brown biotite, white mica (probably muscovite), and garnet. The association of the ore minerals with the metamorphic silicates is so close that the conclusion of their contemporaneous genesis is unquestionable. . . . The microscope reveals the presence here and there of a little carbonate, apparently calcite. The foregoing characteristics indicate that the ore of the Granite mine was deposited shortly after the intrusion of monzonite and is a phase of contact metamorphism."

A comparison of the description of the Granite or Success mine of Idaho with that of the Sullivan of British Columbia given above shows a striking similarity. Both deposits are replacements of argillaceous quartzites by an intimate mixture of zinc blende, galena and iron sulphides, the latter increasing towards the periphery of the ore bodies. The gangue minerals are almost identical in both cases but in the Sullivan, the contact metamorphic silicates are restricted entirely to the ore masses,

while in the Granite or Success mine, the enclosing quartzites are heavily charged with these minerals. Therefore it is concluded that the Sullivan ore masses were deposited under conditions of temperature and pressure less extreme than those under which the Granite or Success ore bodies were formed. Also the fact which is especially worthy of emphasis is the presence of an intrusive monzonite genetically related to the ore deposit in the Granite or Success mine while in the Sullivan, no such intrusion is known; but from the similarity of the deposit in mineralogy and relationships such a mass is doubtless present although probably too deep to be exposed in the future workings of the mine.

With a further decrease in temperature and pressure the conditions, under which the St. Eugene of East Kootenay, the Big Eight and B. B. ore bodies of Idaho[1] were deposited, are reached. In these deposits pyrite, pyrrhotite and the contact metamorphic silicates are less abundant and calcite more plentiful than the Sullivan and Granite ore bodies.

With the entire disappearance of the above silicates and a notable increase of carbonates which point to conditions of deposition less extreme than those of the St. Eugene, we have the Tiger Poorman Lode[2] described by Ransome as follows:

"In the Tiger-Poorman and Standard Mammouth mines siderite is only moderately abundant and the ores contain notable quantities of sphalerite and pyrrhotite. Pyrite and chalcopyrite are comparatively abundant in both mines."

The Wardner mines represent ore bodies deposited under the least extreme of any either in East Kootenay or the Coeur d'Alenes. Concerning these deposits[1] Ransome summarizes as follows:

"In the Wardner mines siderite is most abundant than elsewhere in the district. Sphalerite is rare, pyrite subordinate and pyrrhotite unknown. Garnet, biotite, pyroxene and magnetite entirely absent from these deposits."

[1] D. F. MacDonald: U. S. G. S. Bull. 334, p. 99.
[2] U. S. G. S. Prof. Paper 62, p. 136.
[1] U. S. G. S. Prof. Paper 62, p. 136.

Thus the evidence regarding genesis brought to light in the study of the silver-lead deposits of East Kootenay supports the view advanced by Ransome in 1908 concerning the origin of the silver-lead deposits of the Coeur d'Alenes.

The following table is a summary of the relations existing between the deposits of East Kootenay and the Coeur d'Alenes and showing their probable relations to decreasing temperature and pressure.

Mine.	Country Rock.	Metamorphism of Country Rock.	Ores.	Gangue.	Structural Relations.	Intrusive.
Granite or Success, Idaho	Prichard slate (upper part)	Recrystallized to an aggregate of interlocking quartz grains which enclose pyroxene, mica and garnet	Galena and zinc blende with ABUNDANT pyrite; some chalcopyrite and pyrrhotite present	Mineralized quartzite, garnet, pyroxene, biotite, muscovite, quartz, VERY LITTLE calcite	Replacement deposit in fissured quartzite, not a true vein	Monzonite
Sullivan, East Kootenay	Pre-Creston formation (upper part) lithologically same as Prichard	Recrystallized and altered to chert in close vicinity of ore bodies	Galena and zinc blende with ABUNDANT pyrite and pyrrhotite; some chalcopyrite present	Mineralized quartzite, garnet, pyroxene, biotite and muscovite, quartz, VERY LITTLE calcite	Replacement deposit in well-bedded quartzites, not a true vein	None known
St. Eugene East Kootenay	Pre-Creston formation (upper part) lithologically same as Prichard	Some recrystallization of wall rock shown	Galena and zinc blende, SOME pyrite, pyrrhotite, chalcopyrite and magnetite	Mineralized quartzite, garnet, actinolite, biotite and quartz, SOME CALCITE	Replacement deposit in fissured quartzites, true vein	None known
Tiger Poorman, Idaho	Burke formation		Galena, SOME zinc blende, pyrite, pyrrhotite and chalcopyrite	Quartz and siderite ABUNDANT	Replacement deposit in fissured quartzite, true vein	None known
Wardner Mines, Idaho	Revett formation		Mostly galena, SMALL amounts of sphalerite and pyrite	Siderite in GREAT ABUNDANCE, small amount of quartz	Replacement deposit in fissured quartzite, true vein	None known

THE OCCURRENCE OF OIL AND GAS DEPOSITS ASSOCIATED WITH QUAQUAVERSAL STRUCTURE.

FREDERICK G. CLAPP.

SUBDIVISION OF CLASSIFICATION.

In the classification of oil and gas fields based on geological structure, as proposed in ECONOMIC GEOLOGY,[1] the subdivision entitled "quaquaversal structures" was used to include all those structures where the oil sand dips away in all directions from a central point. On the basis of studies made by the writer in the Pennsylvania, Ohio, Texas, Louisiana and Mexico fields, it seems desirable to subdivide this class into (*a*) the anticlinal bulge or "cross-anticline" type; (*b*) the saline dome type; and (*c*) the igneous core type. With these additions and several minor modifications the classification will become as follows:

CLASSIFICATION OF PETROLEUM AND NATURAL GAS FIELDS.

I. Where anticlinal and synclinal structure exists:
   - (*a*) Strong anticlines standing alone.
   - (*b*) Well-defined alternating anticlines and synclines.
   - (*c*) Monoclines with change in rate of dip.
   - (*d*) Structural terraces.
   - (*e*) Broad geanticlinal folds.

II. Quaquaversal structures.
   - (*a*) Anticlinal-bulge type.
   - (*b*) Saline dome type.
   - (*c*) Volcanic neck type.

III. Along sealed faults.

IV. Oil and gas sealed in by asphaltic deposits.

[1] F. G. Clapp, "A Proposed Classification of Petroleum and Natural Gas Fields Based on Structure," ECON. GEOL., Vol. 5, No. 6, Sept., 1910, pp. 503–521, 8 figs.

V. Contact of sedimentary and crystalline rocks.
VI. In joint cracks of sedimentary rocks.
VII. In crystalline rocks.

Description of Sub-class II. (*a*), the Anticlinal-bulge Type.

This type of structure merges with the types described in sub-class I. (*a*) of the classification, since practically all anticlines consist of alternate contractions and bulges where the formations

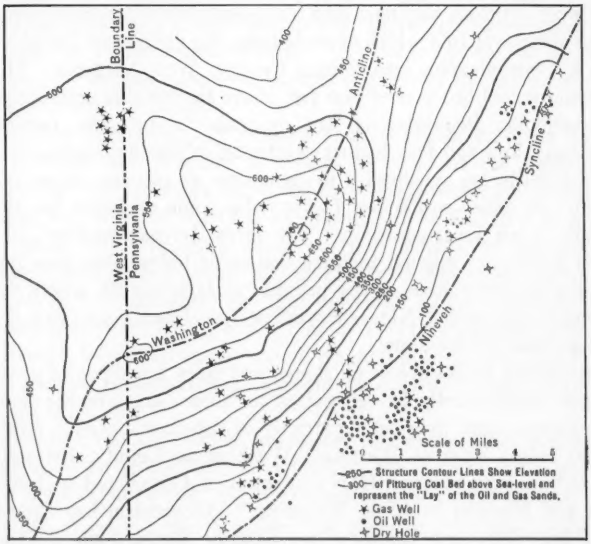

Fig. 54. Map showing anticlinal-bulge type of quaquaversal structure sub-class II. (*a*) in Greene County, Pa., and Marshall County, W. Va.

are respectively depressed or elevated. The type is well illustrated by Fig 54 taken from the Rogersville, Pennsylvania, folio.[1] It is one of the types to which the anticlinal theory, as

[1] F. G. Clapp, Folio No. 146, U. S. Geol. Survey, 1907.

originally promulgated by I. C. White, can be applied without modifications. This is a case of a productive gas field situated on the Washington anticline in western Greene County, Pennsylvania. The structure of the anticline is represented in the figure by contour lines, giving the lay of the Pittsburg coal bed, which is approximately parallel with the gas sands 1,000 to 4,000 feet below them, though some discrepancies exist. It will be noticed that the crest of the anticline dips in all directions away from a central point at a rate of 30 to 250 feet per mile. Northwest it dips toward the Ohio River syncline, southeast toward the Nineveh syncline, and northeast and southwest it descends into a long structural fold which extends from the vicinity of Cannonsburg, Pennsylvania, into Wetzel County, West Virginia. The Pittsburg coal bed is over 700 feet above tide on this anticline at Jacksonville, Pennsylvania, but descends to 420 feet further northeast and 570 feet further southwest in the illustration; and in the bordering synclines it drops as low as 100 feet above sea level. In other words the Jacksonville dome or bulge has the shape of an inverted basin. The term "cross-anticline" has been sometimes applied to these domes or bulges, but it is not always correctly done, as for instance at Jacksonville, where the deepest part of the Nineveh syncline lies directly opposite the highest part of the dome.

Anticlinal bulges are of all shapes and sizes, but those of great length would hardly be recognized as domes and are not here considered, since they belong strictly to sub-class I. (*a*). Anticlinal bulges exist at Westland, Washington County, Pennsylvania,[1] in Jefferson and Harrison counties, Ohio,[2] and in Johnson and Natrona counties, Wyoming.[3] Wegemann has named this last-mentioned feature "the Powder River dome." The present writer has observed the anticlinal-bulge type of domes also at many places throughout West Virginia and Ohio.

In Fig. 54 it will be noted that gas wells are mainly confined to the bulging part of the anticline. While some cases exist of

[1] W. T. Griswold, Bull. 318, U. S. Geol. Survey, 1907.
[2] W. T. Griswold, Bull. 198, U. S. Geol. Survey, 1902.
[3] C. H. Wegemann, Bull. 471–A, U. S. Geol. Survey, 1912.

the absence of gas from good structural domes, as a rule these are productive. When the geology has been deciphered many Ohio gas fields will presumably be found to consist of similar structures.

CLASS II. (*b*), DESCRIPTION OF THE SALINE DOME TYPE.

General Statements.—This type of quaquaversal structure was first described by Hayes and Kennedy in 1903,[1] and more fully by Fenneman in 1906.[2] The saline domes of Louisiana were described by Harris in 1908.[3] The most modern discussion of the Louisiana domes, with reference to oil and gas development, is found in a more recent bulletin.[4] The best description of the geology of the saline dome structures is given by the same writer in ECONOMIC GEOLOGY.[5]

Surface Topography of Saline Domes.—The saline dome type of quaquaversal structure is typical of most of the fields in Louisiana and Texas, in fact of all these fields which are situated within 100 miles of the Gulf of Mexico. The Caddo field and the north Texas fields, however are not included in this type. These domes differ in all particulars from the small mounds known as "ant mounds" or "gas mounds," which are scattered so widely over the Gulf Coastal Plain. It is true that the drilling at Batson, Texas, on an ant mound resulted in finding oil, but this was because the ant mound accidentally overlay a hidden saline dome.

Moreover, it is a mistake to suppose that every dome which is a saline dome geologically is evinced on the surface of the plain by a topographic dome. While instances exist of the occurrence

[1] C. W. Hayes and Wm. Kennedy, "Oil Fields of the Texas-Louisiana Gulf Coastal Plain," Bull. 212, U. S. Geol. Survey.
Bull. 282, U. S. Geol. Survey.

[2] N. M. Fenneman, "Oil Fields of the Texas-Louisiana Gulf Coastal Plain,"

[3] G. D. Harris, Bull. No. 7; "On Rock Salt," Rept. of 1907, Geol. Survey of La., 1908.

[4] G. D. Harris, "Oil and Gas in Louisiana," Bull. 429, U. S. Geol. Survey, 1910.

[5] "Geological Occurrence of Rock Salt in Louisiana and East Texas," ECON. GEOL., Vol. 4, No. 1, pp. 12–34, 1909, 8 figs.

of mounds or small hills overlying the geological domes, the topographic dome is not a necessity to the type. The Welsh pool, the Spindle Top pool and some others are situated where the surface is practically flat.

In southern Louisiana there are five prominent elevations known as the "Five Islands" or the "South Islands," which constitute the most conspicuous land marks in hundreds of miles along the Coast of the Gulf of Mexico.[1] They rise from a few feet to 200 feet above marsh level and have been frequently discussed in literature. In area they are from 200 to 1,500 acres. Salt is found in all of the Five Islands except Cote Blanche.

The following list comprises the known salines in Louisiana, descriptions of which will be found in the Harris bulletin:[2] Grand Cote (Week's Island), Petite Anse (Avery's Island), Belle Isle, Cote Blanche, Cote Carline (Jefferson's Island), Anse la Butte, Prairie Mamou (Jennings oil field), Welsh, Chicot (Pine Prairie), Sulphur, Vinton, Hackberry, Negreet Saline, Coal Bluff saline, Many, Bayou Castor saline, Brown's saline, Cedar Bayou saline, Winnfield dome, Coochie dome, Drake's saline, Price's saline, Reyburn's saline and Bistineau saline.

FIG. 55. Map illustrating surface topography of the Vinton dome, La. (the elevations are shown by structure-contour lines).

The following is a list of the known salines in Texas taken from the same publication:

Davis Hill, Saratoga, Batson, Big Hill, Sour Lake, Spindle Top, Dayton, Humble, Barber's Hill, High Island, Blue Ridge, Hoskins Mound, Damon's Mound, Kiser's Hill, Bryant Heights, Grand saline, Palestine, Steen's saline, Brook's saline, Graham's saline and Stiver's saline.

Some of the salines mentioned have produced oil and some have not, while others have never been prospected. The ordinary topography of a dome is illustrated in Fig. 55.

Geological Structure of Saline Domes.—The configuration of

[1] A. F. Lucas, *Trans. Amer. Inst. Min. Eng.*, Vol. 29, p. 464.
[2] Bull. 429, U. S. Geol. Survey, 1910.

the strata and minerals underlying these domes is a matter of much interest and great importance, as the structure is very different from the normal slight southeastward dip of the Cretaceous and Tertiary beds which underlie the Coastal Plain of Louisiana and Texas. Whether or not there is any particular surface topography indicating a dome, there is a very marked geological protuberance consisting of a sudden upward warping of the strata, as they approach the edge of the dome, so that they may stand nearly vertical round its edges. Several thousand feet of uplift in an area a mile across is not uncommon in these salines. While there are no normal surface Cretaceous beds in Louisiana, there are several salines in which these formations reach the surface in limited areas. Beneath the Cretaceous beds and interlaminated with them in the center of the dome are extensive deposits of rock salt, sulphur, gypsum and sometimes other minerals. As stated by Harris[1] the Cretaceous rocks appearing round the edges of the northern Louisiana salines are not rocks belonging in the uppermost Cretaceous formations, but belong lower in that system.

The term "dome" refers to the shape of the geological struc-

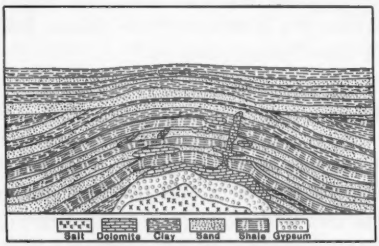

FIG. 56. Cross-section of the Spindle Top oil field, Texas. An example of the saline-dome type of quaquaversal structure (after Hager).

ture, which is illustrated by Fig. 56.[2] In the case of the Gulf Coast oil fields, the underlying formations are domed, whether the surface is so or not. For instance, at Spindle Top the rock

[1] ECON. GEOL., Vol. 4, No. 1, p. 15, 1909.
[2] Bull. No. 7, Geol. Survey of La., 1908.

structure has been figured out very carefully on the basis of well records and found to have a form similar to that illustrated. The cross sections of all salines which have been determined show a more or less dome-like form, although there are great differences in local conditions. As a rule sands and gravels are penetrated for several hundred feet in depth, then limestone or dolomite is penetrated, below which sulphur, gypsum and rock salt are encountered. The character of these minerals is not supposed to have any effect on the existence of oil at the particular point; but the oil has been accumulated from the surrounding strata on account of the upward doming of the sediments having formed a point of interruption. In other words a dome may be considered as an anticline having minimum length.

Salt is believed to exist in all saline domes. The salt consists of 98 to 99 per cent. sodium chloride, except at Belle Isle, Louisiana, where it is saturated with oil. Galenite and sphalerite are also found at Belle Isle in a well drilled on the summit of the dome. Borings made at Belle Isle for oil and sulphur have discovered limestone and sulphur and escaping waters charged with hydrogen sulphide and sulphur dioxide, but the oil from these wells gives no indication of containing sulphur. This oil has a paraffine base and is of 45 degrees Baume, being somewhat lighter in color than Pennsylvania oil.[1]

In the Spindle Top dome, Harris reports that two wells have passed through the porous oil rock and gypsum and penetrated the salt core. Large cavities exist in the dolomite in this field.[2] The size of the cavities can be estimated by large fragments shot from the wells. In some cases drillers report that the tools have dropped several feet into cavities which undoubtedly act as oil reservoirs. The oil-bearing rock is estimated to be 75 to 150 feet thick. A test well near the discovery well at Spindle Top entered gypsum at 1,200 feet, salt rock at 1,650 feet and stopped at 1,900 feet from the surface.

Correspondence of Oil Fields with Saline Domes.—While there are many saline domes in which oil has not been found in

[1] A. F. Lucas, *Met. and Chem. Eng.*, Vol. 10, No. 2, February, 1912, p. 80.
[2] Op. cit.

commercial quantities, it has been found in greater or less quantities in a great many domes, and nowhere else in southern Louisiana and southern Texas. Probably the best known of these is Spindle Top. This dome only rises twelve feet above the surrounding prairie and the surface is only about 235 acres in extent. Although prospecting had been done in 1882, 1885 and 1888 the drillers were prevented by alternating beds of quicksand and gravel from going deeper than 300 feet. Lucas made a final effort and reached the oil rock at 1,120 feet. The pressure was so great that the four-inch drill pipe was shot from the well, carrying away the head-lock swivel and cable, after which there was a great rush of muddied water followed by large fragments of dolomite and fossils. The well then settled to a steady flow of oil, rising to a height of about 200 feet through a six-inch pipe. It flowed continuously for ten days, being finally closed by an eight-inch gate valve. The oil was very offensive in odor, being saturated with hydrogen sulphide and sulphur dioxide so that all houses within a radius of several miles which were painted with white lead, as well as all silver coins, spoons and other silver in houses were blackened. The well is estimated to have flowed about 750 barrels in ten days. The oil rock is porous dolomite, containing some crystals of sulphur.

At Prairie Mamou, Louisiana is the Jennings field, where oil was found at a depth of 1,800 feet. No salt has yet been found in this saline. Harris believes that larger oil resources lie outside the proven field.

In the Welsh field, at Welsh, Louisiana, no salt has yet been found, but, as at Jennings, it is believed to exist. The best wells at Welsh are about 1,000 feet deep. There is no topographic evidence of doming at this field. Sour Lake, Batson, Saratoga and Humdle, Texas, are other saline domes which are the sites of great oil fields. The Anse la Butte dome in Louisiana has produced a few good oil wells, and Pine Prairie, Louisiana, is a new field.

At Sulphur, Louisiana, also known as Bayou Choupique, oozings of petroleum and gas led the Louisiana Oil Company to drill as long ago as 1868. Clays, sands and gravels were penetrated

for 434 feet and then massive gray limestone 60 feet in thickness was encountered. Beneath this limestone alternate layers of pure sulphur and limestone were found for a thickness of 260 feet. Below this were gypsum beds with occasional layers of pure sulphur. Rock salt is as yet unknown at Sulphur.[1] This is one of the greatest sulphur mines in the world. Since the profitable working of the sulphur has taken place, there has been no serious attempt to exploit the oil, although heavy oil still flows from the upper strata into some old test wells. Lucas believes that a large oil field exists here. Some of the Texas salines which have been explored for oil without success are Hoskins, Bryon Heights, Big Hill in Matagorda, Big Hill in Jefferson County, Damon, Kyser, High Island, Barber Hill. Several of the wells, however, had showings of oil and considerable gas, and salt and sulphur were reported in many cases.

Distribution of Saline Domes.—Since the salines of the Gulf Coast may not be conspicuous in the surface topography, and since the surrounding country is flat and without rock outcrops, the question has been frequently asked whether anything can be done in those fields in the way of predicting the occurrence of oil at particular points. While it is not known that any attempt has been made to do this, the undersigned believes that new fields in Louisiana and Texas can be predicted and will be predicted and discovered through a knowledge of the geology of the saline dome type and distribution of structure.

This statement will be understood to some extent when it is explained that these salines are distributed in lines, which are sometimes perfectly straight and sometimes slightly curved, but which extend for many miles across the country. For instance, the Jennings oil field, Cote Carline, Petite Anse, Avery's Island, Week's Island and Belle Isle lie on an absolutely straight line running in a northwest-southeast direction. Anse la Butte, Pine Prairie, Negreet and possibly one or two other salines lie on a similar line, which is approximately parallel to the first. Davis, Batson, Sour Lake and Spindle Top lie on a third line, having

[1] Op. cit.

a similar direction; and a fourth line may be considered as connecting Dayton and Big Hill with several scums of oil which have been noticed floating on the Gulf of Mexico.

Moreover there seem to be east-west lines of salines. The most important of these may be considered as connecting Anse la Butte, Jennings, Welsh, Sulphur, Sour Lake and Big Hill. The first-mentioned system of lines connecting known salines having a northwest-southeast direction, has been mapped by Harris, who has also plotted a northeast-southwest system, but he does not recognize any east and west system. Harris considers that the lines constitute fault lines and that the salines

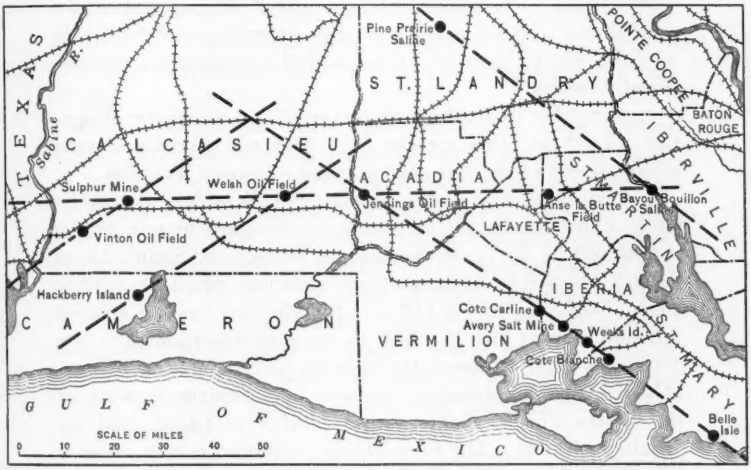

FIG. 57. Map showing distribution of saline domes and hypothetical fault lines in southern Louisiana.

exist at the intersection of two faults. This theory may be literally true, or salines may exist at intervals along these fault lines irrespective of the points of intersection.

Fig. 57 shows the principal supposed fault lines in southern Louisiana, according to the ideas of the present writer.

Practically all of the saline domes which have been discovered

are mapped and described in Bulletin No. 7 of the Louisiana Geological Survey, many of them having been originally mapped by Veach.[1] The alignment of domes was suggested by Hayes and Kennedy,[2] who gave a map showing possible lines of flexures or faults. This alignment was still further mapped out by Harris in his report on oil and gas in Louisiana.[3] The following is a summary of the arguments given by Harris for his faith in the theory of alignment along faults:

1. The abnormal dips found along the southeastern and northeastern margins of the "Sabine Uplift," which is a name given to a southwardly projecting tongue of the Sabine formation in northwestern Louisiana and eastern Texas. It corresponds in a general way with the possible extreme outer limits of the Caddo oil field, which, however, is not a field dependent on quaquaversal structure.

2. A number of the individual domes have an elliptic elongation. Two of these are the Winnfield and Coochie domes, which are drawn out in a northeast and southwest direction.

3. The Bistineau, Kings, Drakes and Winnfield domes lie along a line closely parallel to the northeastern margin of the Sabine uplift. In Texas, Anderson's, Brook's and Stein's domes lie on a line parallel to the Balcones fault line, which lies further west. High Island, Big Hill and Spindle Top lie on a straight line and Damon and Big Hill lie on a continuation of a line formed by three oil scums found in the Gulf of Mexico. Probably the most conspicuous alignment in Louisiana consists of the system which includes the so-called Five Islands and the Jennings oil field. The Five Islands mentioned consist of Belle Isle, Cote Blanche, Grande Cote, Petite Anse and Cote Carline, and lie on a northwest-southeast line along the coast of Vermillion Bay, Cote Blanche Bay and Atchafalaya Bay. The Five Island line is roughly parallel with the Dayton-Big Hill line.

4. Several so-called oil pools or scums of oil found on the surface of the Gulf of Mexico and plotted on the maps of the

[1] A. C. Veach, La. Geol. Rept., 1902, pp. 41–100.
[2] C. W. Hayes and Wm. Kennedy, Bull. 212, U. S. Geol. Survey, 1903, p. 144.
[3] Bull. 429, U. S. Geol. Survey, 1910.

Hydrographic Bureau agree most remarkably in general direction with the Five Islands and would appear like a parallel fault line.

5. Harris gives I. N. Knapp credit for the theory that the line formed by the Five Islands marks the location of a slight anticline, and Harris also states that the lower course of the Mississippi River for from some distance above Baton Rouge to its mouth is determined by a syncline.

6. The strata of the Vicksburg formation seem to have been deposited in a V-shaped area, whose limbs correspond with the two general systems.

7. The isogonic lines, or lines of terrestrial magnetism, are drawn together somewhat along the Sabine Uplift, and this is believed by Harris to account for structural complications in that vicinity.

Harris grouped the faults into two systems, one of them roughly parallel to the Red River fault and the Alabama Landing fault, and second roughly parallel with the Balcones fault in Texas. In order to show that the evidence for these two series is far from conclusive I am mentioning other possible groupings, which may be or may not be true. The most interesting fact has seemed to me that the Anse la Butte, Jennings, Welsh, Sulphur and Sour Lake domes all exist on an east-west line, which seems to be perfectly straight, and is more conspicuous than some of Harris' lines. It would be equally possible to make a line of the Vinton, Spindle Top, Balcones, Blue Ridge and Welsh domes.

Whatever may be thought of the possibility of geological predictions in a flat country like southern Louisiana, it must be acknowledged that the Vinton, Welsh, Jennings and Anse la Butte oil fields are all situated on salines. It must be acknowledged furthermore that the Anse la Butte field, Jennings field, the Welsh field, the Sulphur saline, and at least two salines in Texas which contain oil, lie on an absolutely straight east-west line. It seems strange to an engineer who has studied local conditions that the oil companies make no systematic efforts to

prospect the Gulf Coast fields with the object of discovering new oil-bearing salines, but that hundreds of dry holes have been drilled many miles distant from salines, and with the exception of the Caddo fields, not a single instance of success is recorded outside of a saline. Does not this fact offer a certain future for development in Louisiana and Texas when undertaken in a scientific way?

Origin of Saline Domes.—At least five different theories have been proposed at various times for the origin of the Texas-Louisiana domes. These are as follows:

(*a*) That the domes are old Cretaceous peaks left as monadnocks by denudation, which cut down all the surrounding country. The limited horizontal extent of the salt masses is very particular evidence against this theory as the domes are so isolated and local they can hardly be parts of dissected ridges;

(*b*) That they originated by gas pressure;

(*c*) That water, under tremendous pressure, caused them to appear;

(*d*) That the land surface was projected upwards on the back of deep-seated igneous rock plugs; and

(*e*) That the domes are situated at points of weakness overlying the intersection of fault lines and that heated waters, saturated with mineral in solution, have risen along these points of weakness under intense artesian pressure, carrying with them the sodium chloride, sodium sulphate, etc., which were deposited with their precipitates near the surface when the pressure and temperature were decreased to some extent. The deposition of these minerals was naturally attended by crystallization, the power of which is so great that the entire overlying sediments were pushed upwards and outwards, forming the domes. The topographic character of many of these salines was carefully studied by Veach, and in the report of the Louisiana Geological Survey for 1889 there is a model by him giving Petite Anse in its relation to the surrounding country. If the eroded portion were restored the salt deposit would be found very near the center of the dome. In the vicinity of several of these domes,

there have been secondary centers of crystallization, which have caused minor domes. This last-mentioned theory is the one which is commonly accepted. The theory of crystallization was first propounded by Hill.[1]

Hager's theory was that the domes are due to laccoliths, which do not appear on the surface.[2] His theory would seem to be supported by the existence of volcanic plugs in the Coastal Plain of Mexico, accompanied by many of the Texas phenomena. These plugs are arranged in straight lines in a manner similar to the saline domes. An interesting fact mentioned by Hill is that the oil in the original Lucas well was hot and that hot water has been struck in some cases in the saline domes.

Surface Indications of Oil and Gas.—In a number of localities the saline domes of the Gulf Coastal Plain have been discovered through the means of gas bubbles which rise to the surface about the edges of swamps. This was true at Jennings, Petite Anse and elsewhere. In a number of other cases seepages of brine exist on the sides of saline domes. However, oil, gas and salt springs have no necessary connection with oil fields or salines. To Capt. Lucas belongs the credit for discovering the existence of oil in saline domes. He had the theory in mind for many years before the discovery, and the correctness of his view was demonstrated by striking oil in the Spindle Top field on January 19, 1901. This field has been described by Hill.[3]

Sub-class II. (*c*), Volcanic Neck Type of Structure.

Mexico contains oil fields connected with several types of geological structure, one of which at least is of quaquaversal nature. This type consists of ancient necks of basalt and similar rocks which rise through the Cretaceous and Tertiary sediments of the Coastal Plain, to elevations of several hundred feet. While little drilling has as yet been done in the vicinity of these cones

[1] Op. cit.

[2] Lee Hager, "The Mounds of the Southern Oil Fields," *Eng. and Min. Jour.*, Vol. 78, pp. 137–139, 180–183, July 28 and Aug. 4, 1904.

[3] Robert T. Hill, *Jour. Franklin Inst.*, Vol. 154, pp. 143–156, 225–236, 263–281, 1902.

and the geological structure is therefore somewhat speculative, the general cross section is presumed to be somewhat as in Figs.

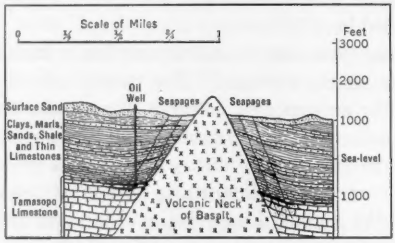

FIG. 58. Hypothetical cross-section through a volcanic-neck in the oil-fields of Vera Cruz and Tamaulipas, Mexico, showing one mode of occurrence of oil in formations having quaquaversal structure.

58 and 59. Dr. I. C. White, to whom these diagrams were shown, has given his opinion that both the types occur; but he agrees with the writer in believing that Fig. 58 is the more com-

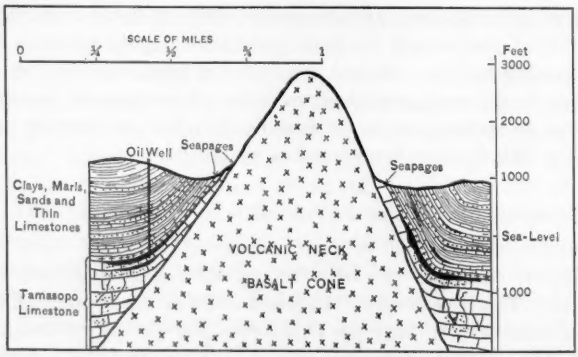

FIG. 59. Hypothetical cross-section through a volcanic neck in the oil-fields of Vera Cruz and Tamaulipas, Mexico, showing a second and probably less common mode of occurrence of oil in quaquaversal structures.

mon of the two. In close proximity to the basaltic upheavals, the Tamasopo limestone and overlying formations have been domed upwards, forming pockets or places of change in rate of

dip at the base of the upheavals and surrounding them, where large deposits of oil have accummulated. In the Tamasopo limestone and San Felipe beds, these oil deposits were presumably concentrated from surrounding portions of the same strata, due to the upheavals mentioned; possibly assisted by the action of heat. The presence of the oil accumulations surrounding the cones are sometimes, although not always, evinced by large seepages of oil in the immediate vicinity.

The surface deposits of Mexico are so thick that whether or not the limestone beds actually reach the surface is somewhat a matter of conjecture, but at any rate the underlying beds are domed upwards by the intrusions, and it is a fact that pockets of oil generally exist there. It would appear that large deposits of oil might be expected in the vicinity of such intrusive masses in all cases where porous sands exist overlain by suitable cover to hold in the oil. Where the impervious covering or cap rock is unusually massive or thick, without fractures, there may be no surface seepages; although seepages do exist in the vicinity of most of the cones, generally not far from their base. Seepages also exist along the sides of volcanic dikes, which radiate from the cones. One case was seen where considerable quantities of asphaltic oil are continually flowing down the sides of a core from a breccia included in the basalt 50 to 60 feet above the surrounding plain. It is supposed that this oil entered the basalt through fissures, which extend inwards from the oil sand, and that its existence and consequent exudation through the basalt was caused by the great pressure under which it exists in the sand.

The volcanic necks of olivine-basalt are scattered at wide intervals throughout the Gulf Coastal Plain of Mexico. They are arranged roughly in lines similar to the lines connecting the salines of Texas and Louisiana, and a large number of dikes follow these connecting lines and radiate in other directions from the necks. The greatest center of volcanic activity in the Mexican Coastal Plain was the Otontepec and Tantima mountains, several thousand feet in height, in the State of Vera Cruz. The

volcanic activity seems to have been less and less at increasing distances from these mountains and has decreased entirely before reaching the Rio Grande River on the north. The majority of the volcanic necks are only a few hundred feet in height, and some of them still less, and it is probable that many such necks exist which never reached the surface.

The largest seepages in Mexico exist within a few miles of the Otontepec Mountains, but seepages are found throughout that part of Mexico, in Amatlam, Tancoco, Tepezintla, Chapapote, Juan Casiano, Cerro Azul and many other localities. Many of these seepages are associated with volcanic rocks. The geological relations of the necks make it certain that they are of more recent origin than the Coastal Plain sediments; although very often no disturbance of the strata can be discovered surrounding them. In the vicinity of the Otontepec mountains, however, there are great sedimentary uplifts which rise many hundred feet above sea level, and in them numerous dikes and intrusive beds of igneous rock have also been seen. The most important point is that large seepages exist encircling the basaltic conical hills.

Lest it should be supposed that the volcanic neck form of structure is given undue prominence, it may be well to mention that this is given simply as the one quaquaversal type noticed among several other Mexican types of structure. Oil fields also exist in Mexico along dikes and faults and on anticlines and possibly on other kinds of domes.

Features Common to All Types of Quaquaversal Structure.—Although there seems to be quite a discrepancy between oil fields of type II. (*a*), II. (*b*) and II. (*c*), they are all similar in many respects. In the first place, in order to hold the oil, the structures must combine all of several factors necessary in every oil field in the world, viz: (*a*) a porous stratum to hold the oil; (*b*) an impervious cover to keep the oil from escaping; (*c*) some sort of geological structure by which the oil, gas and water may have been separated out and the oil concentrated in one locality. In anticlinal and synclinal fields the structure or folding of the beds has acted as factor (*c*); hence we should expect to find gas on

the up-dip side or nearest the crest of the dome, water on the outskirts and oil between, generally at the point of greatest change in dip. That seems to be true in all the fields, though in some of the saline dome fields the dip is so steep that water is pumped from the same well as the oil in large quantities. Moreover gas is not such an important commercial factor in the quaquaversal structure as in oil fields having less dip. An evidence that the change in structure is the concentrating factor is brought from the Louisiana and Texas fields where hundreds of wells have been drilled at a distance from the saline domes with a result that no oil was found. In this class of fields, as in the monoclinal and anticlinal types, the evidence seems to be that the oil has been widely disseminated in the porous strata and that it has ultimately been accumulated at favorable points where the regularity of the dip is locally changed, or where it is interrupted by water, gas, dikes or faults, or by pinching out of strata.

THE ORIGIN OF TURQUOISE IN THE BURRO MOUNTAINS, NEW MEXICO.[1]

SIDNEY PAIGE.

INTRODUCTION.

During the summer of 1910 while engaged in geologic mapping of the Silver City quadrangle, New Mexico, an opportunity was afforded to examine the turquoise deposits of the Burro Mountains, New Mexico. These deposits, famous for the beauty of the gems produced, are located about 10 miles southwest of Silver City, about 1½ miles north of the mining camp of Tyrone. The mines are no longer productive, commercial turquoise having failed in depth.

Edward R. Zalinski has described these deposits in considerable detail in an article published in ECONOMIC GEOLOGY.[2] The conclusions there reached regarding the genesis of the deposits hardly seem justified by the facts presented in this paper, nor with certain general geologic considerations. Also an examination of several microscopic thin sections by the writer, casts some doubt on certain mineral associations emphasized by Zalinski. In the following discussion, an endeavor will be made to reach a conclusion in accord with the facts that are known, supplemented by reasonable deductions from mineralogic relations.

GEOLOGY.

Rocks.—The turquoise is found in granitic and quartz monzonitic intrusive rocks. A pre-Cambrian complex comprising various granitic types was intruded in late or post Cretaceous time by a stock of quartz monzonite and quartz monzonite por-

[1] Published with the permission of the Director of the U. S. Geological Survey.

[2] Zalinski, Edw., "Turquoise in the Burro Mountains, New Mexico," ECONOMIC GEOLOGY, Vol. II., No. 5, pp. 464–492.

phyry. Following this major intrusion, dikes of quartz monzonite porphyry broke through the parent mass and through the surrounding granitic rocks. The turquoise deposits are found both in the granite and in the later intrusive dike rock, a short distance north of the main quartz monzonite mass.

Fracturing and Mineralization.—Much of the region in question has been severely fractured and mineralized. To the south of the turquoise deposits and largely within the borders of the quartz monzonite area are important copper deposits which owe their value to processes of secondary enrichment operating upon lean pyritized fracture zones.[1] The immediate country rock of the turquoise deposits is likewise severely fractured and the most important deposit occupies a fairly well defined fracture zone trending northeast and southwest.

Following or accompanying the fracturing of the granitic and quartz monzonitic rocks solutions, probably though not certainly, of magmatic origin circulated throughout the fractured zone and deposited in fissures and as replacement of the rocks, abundant cupriferous pyrite and quartz. Sericite was abundantly formed and ferromagnesian minerals, hornblende and biotite were either completely destroyed or altered to chloritic products.

Erosion and Oxidation.—There is evidence in a broad areal study of this region to show that the quartz monzonite intrusion took place in late Cretaceous or early Tertiary time. There is also evidence to show that a prolonged period of erosion followed the uplifts of Cretaceous rocks above the sea, and that in places the cover was stripped off the quartz monzonite masses exposing them to oxidizing influences. Of even greater importance in the case under consideration, there is evidence to prove that during Pleistocene time also the rocks in which the turquoise is found were subjected to subaerial erosion, during a period so prolonged, in fact, that planated rock cut surfaces were formed.[2] The turquoise deposits occur from the surface to shallow depths and are thus obviously related to the surface of planation.

[1] Paige, Sidney, "Metalliferous Ore Deposits Near the Burro Mountains, Grant County, New Mexico," Bull. 470, U. S. Geol. Survey, pp. 132–150.

[2] Paige, Sidney, "Rock-cut Surfaces in the Desert Ranges," *Journal of Geology*, to appear at an early date.

The results of these conditions are the usual ones. Copper bearing sulphides have been altered to carbonates and silicates; limonite is formed in great abundance in veins where pyrite was once present, secondary chalcocite coats pyrite and forms commercial ore bodies, and large blocks of ground are completely leached of all copper-bearing minerals. In fact all the signs of extensive alteration in the zone of oxidation are present, in places extending to depths of 800 feet or more, as in the mines about one half mile to the south of the turquoise deposits.

To recapitulate the important geologic and physiographic considerations, quartz monzonitic intrusives have invaded a granitic pre-Cambrian complex. The intrusion was followed by severe fracturing and noteworthy mineralization. Two periods of prolonged erosion permitted thorough oxidation and hydration of the mineralized fracture zones. One of these periods was accomplished by physiographic conditions of such a nature that planated rock surfaces were formed. The turquoise deposits are closely related to a planated surface.

The Occurrence, Mineralogic and Chemical Relations of the Turquoise.

Occurrence.—Zalinski's descriptions furnish an excellent account of the occurrence of the turquoise.

"The turquoise was found in two forms, as vein turquoise filling cracks in the altered granite and as nuggets or concretions imbedded in kaolin.[1]

"The Elizabeth pocket extended from the second level to the surface a distance of 40 feet to 60 feet and the same quality of turquoise was found for 150 feet or more or along the vein. The distance between the walls is 40 feet.

"Some good turquoise was developed on the third level and sparingly on the fourth but here turquoise of the best quality was not plentiful and is associated with *malachite and chrysocolla.*[2] It appears that an excess of copper gives the material a green color and also decreases the hardness. Whether depth is an important factor in the genesis or formation of ideal turquoise cannot be determined but at the present time all of the

[1] Much of the so-called kaolin in the rock sections examined by the writer proves to be sericite.

[2] Italics by the writer.

fine turquoise is found at depths of 100 feet or less. The vein turquoise fills cracks and fractures in the rock and is from one sixteenth up to three fourths of an inch in thickness. Most of it, however, is probably from one eighth to three eighths inches but it has been found up to one and a half inches thick. The nuggets or concretions are usually in the softer portions of the vein and along seams entirely imbedded in kaolin. They are various sizes and shapes, reniform, botryoidal, etc., and make the finest gems.

"Vein rock from near the Elizabeth pocket shows a medium fine to coarse-grained structure, traversed by a more than usual amount of quartz in veinlets and bands up to one half inch or more wide; these are sometimes open and contain cavities lined with quartz crystals. Vein turquoise sometimes contains small quartz crystals penetrating the turquoise from the sides of the vein. Bordering these quartz bands is kaolinized feldspar. The quartz often gives way to bright blue turquoise which partly or entirely fills the vein or occurs in isolated specks. Vein turquoise is often separated from the granite on one or both sides by quartz and also occurs in direct contact with the rock without quartz filling.

"The character of the turquoise varies from place to place along the vein and different kinds are also found closely associated."

Mineralogic Relations.—Two rock sections were examined microscopically by the writer. The relations immediately apparent are that a granular aggregate of quartz and sericite is cut by veinlets of quartz and turquoise. Closer inspection shows that the turquoise is later than most of the vein quartz. And it becomes apparent that the turquoise has been locally replaced partly by a brownish stained opaque substance and partly by a golden yellow mineral identified with a considerable degree of certainty as jarosite ($K_2O3Fe_2O_34SO_36H_2O$).

Considering these minerals individually the following relations are made out. Quartz occurs in three generations. It is found first as a granular aggregate with sericite and represents in large part probably silica set free during sericitization, combined with the original quartz of the rock, which was quite abundant. Second it is found as well defined veinlets cutting the granular aggregate of quartz and sericite. Quartz of this same generation is likewise seen filling open fissures in the granular mass; and third, quartz is found cutting turquoise.

Sericite likewise is found in three generations—first, with granular quartz, second, as replacement veins cutting the vein quartz and third, in veinlets cutting turquoise. Its relations in the second case have this peculiarity, that the sericite crystals penetrate quartz crystals, suggesting solutions of a considerable degree of chemical activity, and in the third case also a small crystal of quartz associated with sericite in a tiny veinlet is apparently penetrated by the sericite. In this case, however, there is the possibility that the quartz and sericite were deposited simultaneously and show relations which may be due to contemporaneity of formation.

The turquoise is later than most of the quartz and sericite (first and second generations). It is cut however by veinlets carrying jarosite, and kaolin (?) and by veinlets carrying either sericite or quartz or both.

The jarosite with quartz and kaolin (?) occupies the latest fractures in the rock which cut all the other constituents.

This bare statement of facts does not clearly set forth all the important relations. For example: The impression is gained from a study of the slides and likewise from an inspection of hand specimens, that two major stages of mineralization have taken place, one characterized by quartz and sericite, the other by turquoise and jarosite. This impression is based first on the intimate association of the sericite with the quartz, the one cutting the other indiscriminately, and second on the association of the turquoise with the jarosite and kaolin (?), many of the fractures in which these latter minerals are deposited strongly suggesting a distinct and single stage. Narrow turquoise veins run out into hair-like veinlets filled with jarosite and taken as a whole are a late phenomenon. Further, the turquoise has filled open fissures lined with crystalline quartz crystals.

The mineralization later than the turquoise consisted in the filling of veinlets with kaolin (?), jarosite, and quartz. This stage, the last, was from the quantitative side a very minor affair. The character of many of the smaller cracks suggest shrinkage

due to sericitization,[1] a process which may have been potent in opening these rocks to downward percolating waters.

Chemical Relations.—It is a recognized fact in chemical geology that a mineral may originate in several ways. The two sets of processes which concern the problem in hand are first, those of deposition from ascending solutions of magmatic origin, as opposed to (second) those processes connected with descending meteoric waters. The writer is strongly of the opinion that in no case can a proper conclusion be reached which fails to consider the geologic relations affecting the problem. What criteria point to a deep-seated origin of the turquoise and what do not? The chemical composition alone, $CuO3Al_2O_32P_2O_59H_2O$, is not diagnostic. Minerals of closely analogous composition (and they are many) are found in situations which point rather conclusively, in some cases, to a deep-seated origin,[2] and in other cases to superficial origin.[3] Nor can mineral association be relied on to furnish any facts diagnostic of deep-seated origin unless it be the occurrence of sericite cutting turquoise and associated with quartz which it has apparently penetrated or replaced. As pointed out before, however, such a relation of quartz and sericite may be due to simultaneous crystallization.

If now the constituents of the turquoise be examined individually from the standpoint of a possible source, two facts are suggestive. Copper is present to the amount of nearly 6.5 per cent. and phosphoric acid to the amount of nearly 30 per cent. The primary mineralization of the region is pyritic. The mines to the south in their lower levels contain pyrite, quartz, sericitized feldspar, and apatite, the latter in astonishingly clear unaltered, and in places, abundant crystals. In other words the waters which deposited pyrite and quartz and which were apparently competent to form sericite, did not attack apatite and brought in

[1] Lindgren, Waldemar, "Metasomatic Processes in Fissure Veins," *Trans. A. I. M. E.*, Vol. XXX., 1901, p. 688.

[2] Apatite $(CaF)Ca_4(Po_4)_3$, Amblygonite $Li(AlF)Po_4$, Hinsdalite $(2PbO-3Al_2O_32So_3P_2O_56H_2O)$, Alunite $(K_2O3Al_2O_36H_2O4So_36H_2O)$.

[3] Chalcosiderite $(CuO3Fe_2O_32P_2O_38H_2O)$ — wavellite $(4AlPo_42Al(OH)_3-9H_2O$.

a very low percentage (only a fraction of a per cent.) of copper.

Turning now to the oxidized zone we find invariably an enrichment of copper and in the turquoise deposits an absence of apatite. The inference is obvious, more strikingly so, when we consider that the turquoise likewise is confined strictly to the zone of oxidation.

An enquiry into the relations between the minerals found in the turquoise deposits and the probable chemical reactions taking place within the oxidized zone are found to be normal rather than otherwise. First as to sericite. Both Rosenbush and Vogt regard sericite as a common alteration product of the zone of weathering. Hickling[1] in an article describing the China clay of Cornwall says: "Muscovite which represents the first stage of the transformation, is a perfectly normal decomposition product, formed whenever potash-feldspar is exposed to the influence of atmospheric moisture." The writer has observed sericite in numerous specimens of apparently fresh potassic igneous rocks, and I am informed by Professor T. Nelson Dale that in most of the New England granites which he has examined, white mica is present as an alteration product. It is apparent therefore that sericite is a stable mineral at the surface, provided conditions are not such as to favor kaolinization. Also, it has probably formed here in two ways, first through primary mineralization by carbonated water,[2] and second by downward circulation of carbonated waters. The sericite found cutting the turquoise may be accounted for in this latter way. The fact that carbonated waters are competent to break down alkaline silicate is too firmly established to need further remark here, and it is the belief of the writer, that if sericite and quartz can result from the breaking down of potash feldspars *in situ*, the same solutions which performed the work are capable of depositing those minerals contemporaneously in veins in turquoise.

Taking up now the reactions which may have occurred to form turquoise. It is a reasonable assumption to imagine a fractured

[1] Hickling, George, "China-Clay: Its Nature and Origin," *Transactions of the Institution of Mining Engineers,* Vol. XXXVI., 1908–9, p. 24.

[2] When this level was buried by much rock now eroded away.

zone within which the important minerals are sericite, quartz, some residual alkalic feldspar, apatite, and pyrite with which is associated a little chalcopyrite.

The oxidation of pyrite will result in the formation of sulphate solutions. Such solutions are capable of dissolving apatite, the alumina of the feldspar, and likewise attacking the sericite to some extent. Such solutions will contain both the sulphuric and phosphoric acid radicles; also copper, iron; potassium and lime. In such a solution, percolating downward, the phosphoric acid radicle on neutralization of the solution would be the first to combine with alumina. This reaction is the normal one in weakly acidulated waters at ordinary temperature. That copper likewise would be precipitated is normal. Just why it should enter into combination in the proper proportions necessary to form turquoise is a point that cannot be answered here, especially as there is evidence that gem turquoise is not always of an exactly identical chemical composition. The balance of all the factors necessary for the reaction were evidently present. The remaining bases may be considered to have passed on in solution.

It is considered probable that this process continued until much of the pyrite and all of the phosphoric acid and unaltered feldspar was depleted. A chemico-mineralogic argument in favor of such a process is found in the jarosite, which followed the turquoise in point of time and which is a hydrous sulphate of potassium and iron. The potassium may well have been derived from sericite and the iron from the pyrite.

Bischof says[1] concerning the analysis of wavellite

$$(4AlPo_4 2AL(OH)_3 \& 9H_2O — \text{Dana}):$$

"The analysis of wavellite by the method of Berzelius and Fuchs shows that phosphate of alumina cannot exist in solution with an alkaline silicate."

This statement is of interest when we consider that alkaline silicates were certainly present in the primary solutions which mineralized this territory. He says also:[2]

[1] "Elements of Chemical and Physical Geology," Gustav Bishof, Vol. II., p. 33, Eng. edition.

[2] Op. cit., p. 33.

"It still remains to be ascertained from what phosphatic mineral the phosphates of alumina in the waters of springs originates. The presence of phosphate of soda in water has already been pointed out and as the soluble salts of alumina are decomposed by phosphate of soda it is possible that it may originate from sulphate of alumina, which is frequently formed in beds of clay by the oxidation of iron pyrite."[1]

Of vivianite ($Fe_3P_2O_8 - 8H_2O$ — Dana) he says:

"Its association with iron pyrite on the one hand and with fossils on the other probably justifies the influence that the iron pyrite was converted, by oxidation, into sulphate and that the phosphate of iron was formed by the reaction of this salt with the phosphate of lime in the fossils."[2]

Also:

"The phosphate of copper in the Virneberg at Rhembreitenbach, seems to have originated from oxidized copper pyrites. It is found chiefly in the outcrop of the lodes, in the clay slate rock and in the neighborhood of open clefts associated with tile ore, chalcedony and quartz. The tile ore, a mixture of earthy oxide of copper and iron ochre has undoubtedly originated from the alteration of copper pyrites; for it is sometimes pseudomorphous after this mineral and occurs in the same position. The occurrence of phosphate of copper at the outcrop of the lode and in the neighborhood of fissures, clearly shows that the water containing phosphate, probably phosphate of lime, came from the surface whether it derived the phosphate from the rock or from organic remains in it."[3]

The bearing of these quotations is obvious: they tend to support reactions such as are postulated above to account for the turquoise.

Conclusions.

Summarizing the facts and deductions which have been presented above, we find that in favor of the hypothesis of deep-seated origin, the following may be arrayed:

1. There is nothing in the inherent chemical composition of the turquoise to exclude such an origin. (Negative argument.)

2. The turquoise is cut by veinlets of sericite and quartz, inter-

[1] P. 34.
[2] Pp. 34–35.
[3] P. 35, Vol. II.

grown in such a manner that heated waters are suggested. (This fact may be interpreted also as contemporaneous growth of sericite and quartz formed in the zone of weathering.)

In favor of an origin in the zone of weathering and at the same time opposed to the deep-seated origin are the following facts:

1. The deposits are found in the zone of weathering, are strictly confined to the uppermost portion of the zone of weathering, and are associated with copper minerals characteristic of the zone of weathering (malachite and chrysocolla).

2. Physiographic evidence proves the existence of long periods of erosion under such conditions, that if we assume the deposits as deep-seated we are confronted with two difficulties, the one to account for the invariable and significant position of all the turquoise of this region with respect to a planated surface, the other to show why the deposits have not either been removed by erosion or altered by the long processes of weathering to which they must have been subjected. To assume that the planated surface has accidentally arrived at the depth where original deep-seated deposition took place would hardly be an argument.

3. There is nothing inherent in the chemical composition of the mineral to exclude it from an origin in the zone of weathering. In fact there are many hydrous phosphates of a more or less analogous composition which have undoubtedly originated in this way. (Negative argument.)

4. A search for the source of the material found in the turquoise indicates that the solutions producing primary mineralization in this region were probably inadequate. Apatite was not attacked and copper was introduced in very sparing quantity. On the other hand, in the zone of weathering apatite has been removed and a concentration of copper is the normal process.

5. Seeking the possible solutions from which the turquoise might have formed, we have some chemical data to show that phosphates of alumina probably did not exist in the solutions which caused the primary mineralization of this region. On the other hand we have in the zone of weathering a potent solvent for all the constituents found in the turquoise,—sulphate solutions

formed by the oxidation of pyrite known to have been present. Likewise the constituents of the turquoise were present at the time oxidation began to be effective.

6. Chemical laboratory experiments in the cold agree with the assumption that if the sulphuric and phosphoric acid radicle are present in a weak acid solution which gradually becomes neutralized, the phosphoric acid first will combine with alumina. Mineralogic evidence observed in rock sections indicates that such processes have taken place and that the depletion of phosphoric acid and alumina by leaching resulted finally in the precipitation of sulphates of potassium and iron probably derived from sericite and pyrite.

DISCUSSION

This department has been established by the editors in order to afford to those interested in questions relating to economic geology an opportunity for informal discussion. Contributions are cordially invited either in the form of discussion of more formal papers appearing in earlier numbers or bearing upon matters not previously treated. Letters should be directed to the Editor, Sheffield Scientific School of Yale University, New Haven, Conn. The full name of the author should be attached to all communications.

THE TEACHING OF ECONOMIC GEOLOGY.

Sir: In entering the discussion opened by Mr. Stewart, the importance of the subject justifies a consideration not only of the courses in geology but also of the entire course to be prescribed for students of mining engineering. The necessity of a thorough discussion of this matter becomes apparent upon looking over the catalogues of the schools giving courses in mining engineering and finding the required work differs from one extreme where no mineralogy is given, and an introductory course only in geology, to the other extreme where it is possible to take geology almost to the exclusion of other engineering subjects. Further even among members of the profession there is some difference of opinion as to the definition of a "mining engineer." Some would not consider the consulting specialist in ore deposits as a "mining engineer" but as a geologist only, making mining engineering as a branch of civil or mechanical engineering applied to mining, while others would allow the expert accountant employed in mining to be designated a "mining engineer." Further, the variety of work that may fall to the mining engineer is great, and the training of the engineer practicing coal mining, busied with the problems of mechanical engineering and the methods of coal extraction and needing a minimum of geology, or that of the one

who has specialized in open pit mining in northern Michigan, and who should be really a railroad engineer, differs as much from the studies that best prepare a man for exploring and mining a metalliferous deposit in the west, as the training of a mechanical engineer ordinarily differs from that of a civil engineer.

Speaking of the mining engineer who is training for practice in the west, he should have a knowledge of general engineering with a special training in the science of ore deposits, and the methods of mining them. With a field as broad as this it is evident that a man can only get a foundation in school on which he must build afterwards. His further education is to be obtained in the offices of the mining companies or in the mine stopes, and he must return for his instruction and his pay, accurate, but generally elementary and routine engineering. For this reason, and because the boy must get a start and earn bread and butter, too much stress cannot be laid on drafting, simple designing, surveying and assaying, lines along which he will find his opening in the mines. It is highly desirable of course, for the mining engineer, to take at least a bachelor's degree in civil or mechanical engineering, with the addition of the introductory courses in mineralogy and geology, and then get his degree of "engineer of mines" after two years' advanced work.

The prospective young mining engineer should choose whether he will devote himself largely to engineering (civil and mechanical) studies, getting at least something more than the rudiments of these, and taking the minimum of geology, sufficient to give him some foundation for his later practical study of ore deposits, learning at least enough to call in an expert along these lines when he gets beyond his depth, or whether to learn thoroughly the rudiments of civil and mechanical engineering, and devote himself to getting a geological foundation, that will enable him, after the practical experience, to carry out a modern geological research of an ore deposit. To do this however will require more than the ordinary four years' course leading to the bachelor's degree in mining engineering.

Finally the question arises as to what difference is to be

made between the training of the mining engineer and the metallurgist. Theoretically there might seem to be but little in common in the mining of and evaluating of an ore deposit, and the reduction of the ore from the same. A metallurgist in an eastern copper refining plant for instance might have little need of the knowledge of the geology of copper deposits or the methods of mining the same, but even here, success in the refining of copper will make him a mining man in the eyes of his friends, and they may even induce him to come west and examine a mine, which will probably end in disaster for himself and friends as occurred in a case I have in mind. It is self evident that the mining engineer should have some knowledge of the principles of ore dressing, milling, and smelting. The young metallurgist will rarely get into a smelter or mill and stay there. If successful later he may be called on to manage both mine and mill and to examine and value mining properties. The majority of courses laid out for the B.S. in metallurgy are open to the severe criticism that the student is required to spend much time in mechanical and manipulative details, which can be better learned outside, and these are given to the exclusion of the study of principles of other branches, without the knowledge of which he will be handicapped in his advancement in the profession. I believe that the time is ripe for a revolt against the common practice of training artisans and calling them engineers.

With the above introduction in mind, we may consider the work in geology that should be given the mining engineer under the two following cases. (I.) For the student studying civil and mechanical engineering in order to apply it to mining, or metallurgy, with a minimum of geology. (II.) For the student studying the fundamentals of general engineering, and covering the science of ore deposits more thoroughly.

For both classes geological instruction may begin in the Sophomore year. This may consist in a course in blow pipe analysis for the first term, and some introductory course in geology for the second term. The writer does not believe in a course for the beginner in identifying minerals by physical tests. It becomes

a course in guessing and teaches the student inaccuracies. Our experience with students who have taken such courses is that they do harm instead of good. The geology course can introduce the student to a few salient facts regarding physiographic and geologic processes, to rocks and their occurrences and to some features of ore deposits. During the Junior year crystallography and descriptive mineralogy will form a year's course. The student should handle and learn to recognize as large a number of minerals as possible, and the geological occurrence of the minerals should be emphasized. However the course in mineralogy should be given from the mineralogical standpoint rather than the geological standpoint, and not by the man who gives the later courses in ore deposits. This is for the purpose of broadening the methods of presenting the subjects relating to ore deposits, and widening the viewpoint of the student. The year's course in Junior geology would be one of the heavy courses of that year. Laboratory courses should form an important part of the work including studies of topographical and geological maps, stereography applied to structural geology and graphic solution of problems in faulting, classification and identification of rocks, etc., etc. Physiographic and structural geology, the study of underground water, and metamorphism can be taken up in some detail during the first 3 months. Historical geology can be cut down to two months and the last four months devoted chiefly to chemical geology and ore deposits. Certain important applications of chemistry and physical chemistry should be discussed here. For instance it should be shown by numerical calculation how the theory of dilute solutions and mass action, explain all the various phenomena of metasomatic replacement. Hydrolysis and its geological application should be discussed in detail, as well as some of the geological applications of the phase rule. A brief study of ore-forming processes, such as replacement, secondary enrichment, etc., with a classification of ore deposits will finish the course.

The above-mentioned work is all that can probably be required of students not going any farther than the bachelor's degree and

under the first group mentioned above, although if possible the senior course in the study of nonmetallic products and ore deposits should be taken. The field geology trip should be given either between the junior and senior year or during the latter. In schools in the west with field problems close at hand, it can be given during the senior year with some advantages over the former plan. During the senior year the usual courses in type fossils, in the economic geology of the nonmetals and of ore deposits, and in microscopic crystallography and petrography should be given. The nonmetallic products in the economic geology course, can be taken the first term. The "Mineral Resources" is the most satisfactory textbook for this, and statistical and graphic methods of investigation can be emphasized. The course in ore deposits is the one specially discussed by Mr. Stewart. If the student has not had his attention directed to the subject in the sophomore and junior years, and especially in the case of an eastern boy who has never seen a mine or ore deposit, there is much force in the arguments for more emphasis on ore-forming processes. Further, the attempt is hopeless to follow the condensed descriptions given in such a book as Thomas and MacAllister's "Geology of Ore Deposits," which is an artificial arrangement of condensed paragraphs with geology left out, on a large proportion of known ore deposits.

The attempt to classify ore deposits under certain definite groups, such as magmatic segregations, contact deposits, vein deposits of various types, etc., is neither very satisfactory from the scientific or the teaching standpoint, especially because any one mineral district or even deposit may show a number of these varieties of ore deposition, modified by a variety of secondary changes. The writer has found a combined geographic and geological basis of classification preferable. Since a large proportion of the American students do not have the command of foreign language to make the study of foreign occurrences satisfactory, attention has to be confined to American examples. Further, the older (and unfortunately some that are not old) descriptions are written by those not trained in the science of ore deposits, so that

the literature studied will be largely that of the government survey, some of that published by the state surveys, and a few contributions of engineers of standing not connected with geological survey organizations.

The selection of the groups of ore deposits will gradually develop a genetic and geological classification. A study of the Mother Lode group of quartz veins, extending up into Alaska will bring out the characteristics of gold quartz veins of the deep-seated kind connected with Mesozoic—early Tertiary granitic intrusives. The many interesting structural details of this group can only be brought out by a study of the detailed geological maps of the ore regions, and the correlation of the group as a whole by a study of the geological map of the country. The writer believes that it is not too much to say that a satisfactory study of the ore deposits of the United States has now been made possible by the publication of the geological map of the country just issued.

The study of the great group of Arizona-New Mexico copper and lead-zinc deposits around monzonite and more acid intrusives, must be prefaced by a structural study of the region. The rôle of the zone of structural weakness skirting the plateau province, running from northwest to southeast in Arizona and curving to a direction from southwest to northeast in New Mexico in governing intrusion and ore deposition will be remembered by every student who has discovered the fact for himself by study of the map. The various complicated phases of ore deposition induced around these intrusions can only be mastered after a thorough study of many of the occurrences.

The details of ore deposition in any region are so closely related to structural details brought out by the geological map, that the suggestion to lay less stress on the geology of the ore occurrences meets with the decided disapproval of the writer.

Towards the close of the senior year, the student will have some idea of magmatic differentiation, etc., and the study of maps and rock descriptions of selected regions, will bring out the occurrence of progressive differentiation, and the occurrence of later satellitic dikes cutting the ore deposits may locate the metal-

lization as one of the series of events in the rock differentiation. In the Lake Superior-Canadian region for instance, it is difficult to see how the relation of ore deposits to progressive differentiation can be appreciated at Sudbury without a study of geological maps and descriptions, or the still closer relation of the ore solutions that formed the original veins at Cobalt, to the pegmatite differentiate of the Keweenawan diabase; and finally with the help of the last Monograph of Van Hise and Leith, and the general geological map of the region, the varied ore deposition of the Keweenawan period, including iron, copper, nickel, cobalt, and rich silver ores, can be worked out by the student in a way that will leave a lasting impression on him.

Further discussion of this method of attack is unnecessary. Towards the end of the course condensed descriptions of foreign occurrences and relations can be introduced by the instructor. In the course outlined the student cannot take up in a satisfactory manner the microscopic examination of ores and gangues during the senior year, but he can learn much from polished hand specimens, with assistance of the binocular microscope, and the study of the numerous microphotographs in the government's publications. The graduate and research courses are arranged to fit the student and subject and need not be discussed here.

In closing, it may be remarked that the writer has met a large number of civil, constructing, and electrical engineers, who have come to the western mining districts to practice their profession. Almost without exception, these men have expressed regret that they had not studied the rudiments of geology and the science of ore deposits, and therefore it would be a good thing if the eastern engineering schools would suggest to those students who have any idea of practicing in a mining country to take the elements of geology.

C. F. Tolman, Jr.

THE ORIGIN OF THE ANHYDRITE AT THE LUDWIG MINE, LYON COUNTY, NEVADA.

Sir: The recent article by Dr. Rogers on the occurrence of gypsum and anhydrite at the Ludwig Mine[1] has been of especial interest to me as I am not only familiar with the deposit he describes, but have also visited the deposits he mentions at Lovelock and Mound House.

At the Ludwig Mine the derivation of the gypsum from the anhydrite is plainly evident and the evidence advanced by Dr. Rogers leaves little doubt as to its origin. In considering the origin of the anhydrite however I believe he failed to consider one possibility that seems to be more in accord with the observed facts.

It is true that the deposits of gypsum at Ludwig, Mound House, and Lovelock have much in common. The sedimentary strata of which the gypsum is a part are strikingly similar in appearance and lithological character at these localities. Triassic fossils have been found in the vicinity of all three deposits in rocks apparently belonging to the same series.[2] A grano-diorite similar to and probably identical with the early Cretaceous grano-diorite of the Sierras intrudes the strata associated with the gypsum in all three localities. As the Triassic strata are notably gypsiferous throughout the Western Interior there seems to be little reason for doubting that these gypsum deposits are contemporaneous and formed under similar conditions.

At Lovelock, in contrast with the other two localities, the intruded igneous rock is several miles to the north, and the sediments in the vicinity of the gypsum deposit are unaltered. Here much of the gypsum is in thin layers interstratified with thin beds of limestone. While some of the gypsum is evidently of

[1] This journal, Vol. VII., pp. 185–189, 1912.

[2] Louderback, G. D., U. S. G. S. Bull. 223, pp. 112–118, 1904; Smith, D. T., *Bull. Dept. Geol. Univ. Calif.*, Vol. 4, p. 9, 1904. I have also collected Triassic fossils from the strata near the Ludwig Mine. See also Louderback, G. D., G. S. A. Bull., Vol. 15, p. 334, 1904, for an additional occurrence of gypsum in the Triassic strata of Nevada.

secondary origin yet there is little doubt that the greater part of it was originally deposited as a part of the sedimentary series.

At Mound House and Ludwig the grano-diorite is in close proximity to the gypsum, and the associated sediments have been greatly metamorphosed. At the Ludwig Mine many dikes of the grano-diorite are intruded into the sedimentary strata and it is my recollection that at least one dike cuts the gypsum. As a result of the intrusion the limestones are frequently completely altered to garnet rock and other metamorphic minerals are abundant.

The sedimentary origin of the gypsum at Ludwig has possibly been questioned. Dr. Ransome in his report on the Yerington district[1] in speaking of the Ludwig Mine states that the foot wall of the lode has been altered to solid alabastine gypsum for a depth of fifty feet by sulphate waters resulting from the oxidation of the sulphides of the lode. If he refers to the deposit under discussion, which is the only massive gypsum in the vicinity of the lode of which I am aware, I do not think his hypothesis is correct.

As Dr. Rogers shows in his cross section (*q. v.*), there is a thick bed of massive limestone between the lode and the gypsum. It is rather difficult to conceive the conditions that would permit the complete alteration of a bed of limestone a hundred feet from the lode without some alteration taking place in the intervening limestone. The fact that there has been secondary sulphide enrichment in the lode would imply that the sulphate solutions traveled down the lode rather than out through the foot wall. Further, if the gypsum resulted from these solutions it is strange that copper minerals are not found in it. Again it is very difficult with our present knowledge to frame a hypothesis for the formation of the anhydrite from the cool vadose circulation; and there is no doubt as to the secondary origin of the gypsum from the anhydrite. While the gypsum and the lode are parallel in strike and dip, the gypsum overlaps the lode by several feet to the south. It is probable that the association of the gypsum and the lode is accidental and caused by the selective replacement of one

[1] U. S. G. S. Bull. 380, pp. 112–113, 1909.

of the beds of the sedimentary series, of which the gypsum is a member, by the mineralizing solutions connected with the intrusion of the grano-diorite.

Dr. Rogers considered the anhydrite to have been deposited as such in enclosed arms of the sea or in interior lakes. Experiment has shown however that anhydrite is deposited from solution only from warm concentrated brines.[1] None of the Nevada deposits under discussion have salines associated with them, nor is there any evidence that suggests that they were once present and have since been removed. On the other hand the association of gypsum and limestone is of rather common occurrence and is found wherever the mineral matter dissolved in the waters of the sea or inland lakes has been incompletely precipitated by their partial evaporation.

Therefore it is more probable that the anhydrite at Ludwig was originally deposited as gypsum as was the contemporaneous deposit at Lovelock, and not as anhydrite as supposed by Dr. Rogers. This gypsum was afterwards dehydrated and recrystallized when the grano-diorite intruded and metamorphosed the associated sediments, and the vadose circulation has since rehydrated the anhydrite to gypsum.

J. CLAUDE JONES.

[1] Clarke, "Data of Geo-chemistry," U. S. G. S. Bull. 491, p. 215, 1911.

REVIEWS

The Mineral Resources of the Llano-Burnett Region, Texas, with an Account of the Pre-Cambrian Geology. By SIDNEY PAIGE. Bulletin 450, U. S. Geological Survey, 1911, pp. 103. Maps and illustrations.

The Central Texas Llano-Burnett pre-Cambrian area, a nearly level, oval-shaped basin, walled by Paleozoic and Cretaceous rocks, consists of a northwest-southeast folded complex of major granites and minor basic igneous rocks, intrusive into two superincumbent, dominantly sedimentary gneiss schist series; the lower generally acid and light colored; the upper prevalently dark colored and basic. Conformably interlayered with the gneiss-schist series, particularly the lower, and showing the same metamorphism, occur thin lenses of alternating magnetite, quartz, and silicate bands, locally ore. Paige believes them sedimentary, but finds their generally low phosphorus content unique, apparently disregarding the surpassing tonnage of low phosphorus sedimentary iron ore of Brazil and the Lake Superior region.

Mr. Paige seems to feel the necessity of proving that sedimentary iron ores exist in formations of various periods, and cites a considerable number of cases from which he concludes that "it is therefore natural that bedded iron ores derived from primary deposits should be present in the pre-Cambrian complex."

EDWARD STEIDTMANN.

RECENT LITERATURE ON ECONOMIC GEOLOGY.

COMPILED BY

ADOLPH KNOPF and J. B. UMPLEBY.

METALLIFEROUS DEPOSITS.

COPPER.

The Enargite Deposit in Taiwan. By YUZO DEGUCHI. Journ. Geol. Soc. Tokio, Vol. 19, 1912, pp. 13–15.

Enargite in workable amounts occurs in replacement deposits and auriferous quartz veins enclosed in Tertiary sedimentary rocks pierced by dacite. It is associated with pyrite, barite, alunite, and sulphur; the formation of the alunite was in part coeval with that of the enargite.

Geology and Ore Deposits of the Index Mining District, Wash. By CHARLES E. WEAVER. Wash. Geol. Survey, Bull. No. 7, 91 pp. Olympia, 1912.

Index is a small copper-producing district situated on the west slope of the Cascade Mountains in the central part of Washington. The ore occurs in narrow veins which traverse granodiorite, quartzite, aplite, and andesite porphyry. U.

GOLD AND SILVER.

The Classification of the Rocks of the Western Australian Goldfields. By J. A. THOMSON. Geol. Mag., Vol. 9, pp. 147–152.

The "Auriferous Series" consists predominantly of schistose basic rocks and the gold-bearing deposits lie in the contact aureoles of intrusive granites.

Die Golderzlagerstätten und das Braunkohlenvorkommen der Rudaer Zwölf-Apostel-Gewerkschaft zu Brad in Siebenbürgen. By F. SCHUMACHER. Zeit. pr. Geol., 1912, pp. 1–85.

The classic gold deposits of Transylvania have lapsed into decay, but others, not well known, have come to the fore, among which those of Brad are economically most important. The veins are enclosed in regionally propylitized andesites and are richest in prox-

imity to the old volcanic vents. They were filled by thermal solutions ascending along tectonic fissures. The upper parts of the veins show notable impoverishment, succeeded below at water level by a zone rich secondary gold ore. Miocene coal measures are exploited in a nearby field to supply fuel for the gold mines.

A Reconnaissance of the Jarbridge, Contact and Elk Mountain Mining Districts, Nevada. By F. C. SCHRADER. U. S. Geol. Survey, Bull. 497, Washington, 1912, 162 pp.

The rock formations of these districts include Paleozoic sediments intruded by Cretaceous (?) granodiorite and capped by late Tertiary eruptives, principally rhyolite. Two distinct periods of mineralization are recognized. The earlier is assigned to the Cretaceous; the later to the Miocene. The Jarbridge deposits, representing the later epoch, are gold-bearing quartz-adularia-calcite veins. The deposits of the Contact and Elk Mountain districts conform to the margin of the granodiorite and are characterized by auriferous and argentiferous copper ores. U.

IRON.

Comparaison entre les Minerais de Fer Huroniens des Etats-Unis et les Minerais de Fer Oolithique de France. By L. CAYEUX. Compt. rend., Vol. 153, 1911, pp. 1188–90.

Takes issue with Van Hise, Leith, and Spurr concerning the inorganic origin of the oolites of the iron-bearing rocks of Lake Superior. There exists a strong analogy of structure and composition between the iron minerals of the Huronian of the United States and the oolitic minerals of France.

Etude sur les Gisements de Fer de l'Algérie. By M. DUSSERT. Annal. de Mines, 1912, pp. 69–133, 135–256.

The most important deposits of iron ore in Algeria are due to the metasomatic replacement of limestone beds. The production during 1910 was 1,105,000 metric tons, carrying 50 per cent. metallic iron.

Informe acerca de la Naturaleza de los Minerales de Hierra de Mayarí. By J. R. VILLALON. Revista Soc. Cubana de Ing., Vol. 4, 1912, pp. 31–47.

The iron deposits of Mayarí, Cuba, have originated from the lateritization of serpentine.

Les Reserves Mondiales in Minerais de Fer. By L. DE LAUNAY. Annal. Geog., Vol. 21, 1912, pp. 97–103.

A brief discussion of the iron ore resources of the world, bringing out the fortunate position of France.

Ninth General Report of Md. Geol. Survey. By Wm. Bullock Clark and others. Baltimore, 1911, 348 pp.

The major portion of this report is devoted to the iron ores of the state, including a history of the local industry. U.

Note sur L'importance Probable du Gisement Ferrifére de L'Anjou. By M. E. Bellanger. Annal. de Mines, Vol. 20, 1911, pp. 452–456.

A reserve of one billion tons of iron ore, ranging from 46 to 55 per cent. metallic iron, is estimated.

PLATINUM.

Estudio acerca de la Dunita Platinifera de los Urales. By S. Pina de Rubies. Revista de la Real Acad. Ciencias, Madrid, Vol. 10, 1911, pp. 151–186.

Essentially a chemical and petrographic study of the platiniferous dunites of the Urals.

NON-METALLIC PRODUCTS.

ASBESTOS.

The Production of Asbestos in 1911. By J. S. Diller. Advance chapter from Min. Res. of the U. S. for 1911. U. S. Geol. Survey, 1912, 9 pp.

The total domestic production of asbestos for 1911 was 7,604 short tons valued at $119,935, an increase of 106 per cent. in quantity of the production of 1910. Only four states, Georgia, Vermont, Virginia, and Wyoming produce this mineral. Their total output is about 8 per cent. of that of Canada. U.

COAL.

Coal Near the Black Hills, Wyoming-South Dakota. By R. W. Stone. U. S. Geol. Survey Bull. 499, 1912, 66 pp.

Describes the geology and coal resources and makes special mention of a coking coal which in some mines averages about $2.45 in gold and $.28 in silver per ton. This coal is used in the smelting operations at Deadwood, S. Dak. U.

Geography in the Development of the Alaska Coal Deposits. By Alfred H. Brooks. Annals of the Assoc. of Amer. Geographers, Vol. 1, 1912, pp. 85–94.

The coal supply of the Pacific slope of Alaska is estimated as three-fourths of the total coal supply of the Pacific slope of North

America. The coals are so situated geographically as to be the natural source of fuel for the western border of the continent. Their chief rival at present is the petroleum fields of California which are now supplying fuel to Alaska. U.

Sur la Composition et le Gisement de la Paraffine de Schistes bitumineux du Bassin Houiller du Pas-de-Calais. By CH. BARROIS. Annal. Soc. Geol. du Nord, Vol. 40, 1911, pp. 157–170.

The Formation of Coal Beds, Pt. II. By JOHN J. STEVENSON. Proc. Am. Philos. Soc., Philadelphia, 1911, pp. 519–643. U.

Geology and Coal Fields of the Lower Matanuska Valley, Alaska. By G. C. MARTIN and F. J. KATZ. Bull. U. S. Geol. Survey No. 500, 1912, 98 pp., with 5 maps.

This report embodies a detailed investigation of the Matanuska coal field, which with the exception of the Controller Bay field, is the only coal field of Alaska likely to have any immediate commercial value. The coal-bearing area comprises at least 74 square miles and possibly 98 square miles. High grade coking coal underlies 52 square miles; low grade coal near black lignite underlies the remainder. The coal measures are 2,000 feet of sandstone and shale carrying an abundant Eocene flora. The rocks are folded and faulted, and intruded by numerous masses of diorite porphyry, albitophyre, gabbro, and diabase. The region is heavily drift-covered, and because of the complicated structure and numerous intrusions, no tonnage estimates are attempted.

Les Variations de Composition du Charbon dans Certaines Veines d'Aniche. By CH. BARROIS. Annal. Soc. Geol. du Nord, Vol. 40, 1911, pp. 177–186.

OIL AND GAS.

The Accumulation of Oil and Gas in Sandstone. By R. H. JOHNSON. Science, N. S., Vol. 35, 1912, pp. 458–459.

The accumulation of oil and gas in sandstone is aided by surface tension and capillarity phenomena.

Die Bildung der Hauptbestandteile des Erdoels. By C. ENGLER. Petroleum, Vol. 7, 1912, pp. 399–403.

Petroleum is derived from organic remains through a long chain of transformation products; the direct experimental synthesis of oil from fats and waxes is therefore now mainly of historical interest.

Das Erdoelvorkommen in Galizien in Lichte neuer Erfahrungen. By LADISLAUS SZAJNOCHA. Mitt. Geol. Gesell. Wien, Vol. 4, 1911, pp. 17–36.

Discusses the geology, genesis, and production (5 per cent. of the world's production) of the Galician oil fields.

Estado Actual y Porvenir de la Industria Petrolifera en el Peru. By R. A. DEUSTUA. Bol. Soc. Ingenieros, Lima, Peru, Vol. 14, 1912, pp. 57–90.

Discusses the present condition and future possibilities of the petroleum industry of Peru.

Uber den Geologischen Bau der Region der Schlammvulkane und Oelfelder von Berca und Beciu bei Buzeu in Rumänien. By H. PREISWERK. Zeit. pr. Geol., 1912, pp. 86–95.

The oil pools are situated along an anticlinal axis; the principal oil horizon occurs within a series of soft sandstones and marls of early Pliocene age, aggregating 600 meters in thickness.

The Influence of Petroleum on the Geothermic Gradients in the Echigo Oil Fields. By G. KOBAYASHI. Journ. Geol. Soc. Tokio, Vol. 19, 1912, pp. 9–12.

The geothermic gradients in the fields have smaller values than the normal gradient and range from 15 to 28 meters per degree Centigrade.

Die Oel- und Wasser-Horizonte von Boryslaw-Tustanowice. By RUDOLF ZUBER. Petrol. Zeit., 1912, pp. 457–460.

The principal oil horizon of East Galicia is the Lower Oligocene, which is also the principal salt water aquifer. Other oil and water horizons occur, both above and below this one, and the importance of sealing off the water is dwelt on.

Oil Investigations in Illinois. By RAYMOND S. BLATCHLEY. Trans. Ill. Acad. Sci., Jan. 25, 1912, pp. 85–96.

The State Geological Survey has prepared contour maps of each oil sand in several of the fields and is endeavoring to determine the relation of the quantities of oil, salt-water, porosity of the sand, etc., to the structural features. In addition the structural anticlines in the southern part of the state have been platted and numerous sections prepared. U.

Outlines of Oilfield Geology. By T. O. BOSWORTH. Geol. Mag., Vol. 9, 1912, pp. 16–23, 53–59.

Shortage of Refinable Crudes. By R. H. JOHNSON. Nat. Petrol. News, 1912, pp. 42–44.

Gives a brief inventory of the underground reserves of the fuel and refinable crude oils of the U. S. Concludes that the production

of "light oil" can not keep pace with the increasing consumption, and advocates that the production statistics should discriminate between the output of fuel oil and refinable crudes.

PHOSPHATE.

The Natural Phosphates of Tennessee, Kentucky, and Arkansas. By WILLIAM H. WAGGAMAN. U. S. Dept. of Agri., Bureau of Soils, Bull. No. 81, 1912, 36 pp.

The report describes the conditions in the several fields, outlines the modern methods of mining and handling the rock, and outlines the uses of the products and by-products of the industry. U.

SALINES.

Potash Salts. Advance chapter from Min. Res. of the U. S. for 1911. By W. C. PHALEN. U. S. Geol. Survey, 1912, 31 pp.

Outlines the work of the Federal Government in the search for potash, states results of the year's investigations, and reviews the present status of the potash industry. U.

Die Verwendung des Leucitophyrs ("Phonlithmehl") als Kalisilikat. By H. STREMME. Kali Zeit., 1912, pp. 153–161.

That portion of the potash of leucite, nepheline, and the glass base soluble in hydrochloric acid is easily available as plant food, whereas that in sanidine is unavailable.

WATER RESOURCES.

Gaging Stations Maintained by the U. S. Geol. Survey from 1888 to 1910 and Survey Publications Relating to Water Resources. By B. D. WOOD. U. S. Geol. Survey, W-S Paper 280, 1912, 102 pp. U.

Surface Water Supply of the United States. Part II. South Atlantic Coast and Eastern Gulf of Mexico. By M. R. HALL and J. G. MATHERS. U. S. Geol. Survey, Water Supply Paper 282, 1912, 109 pp. U.

Water-Powers of North Carolina. By the Hydrographic Div. of the U. S. Geol. Survey. N. C. Geol. and Econ. Survey Bull. No. 20, Raleigh, 1911, 380 pp.

The water-powers of North Carolina are considered here as the most important natural resource of the state. The bulletin includes tables relating to the flow of the principal streams and many of the smaller streams and tributaries giving the amount of available water

and to what extent its utilization may be increased by storage and reservoirs. U.

REGIONAL.

The Geology of the Greymouth Subdivision, North Westland, New Zealand. By P. G. MORGAN. New Zealand Geol. Survey Bull. 13 (N. S.), 1911, 159 pp.

Fifteen pages of this bulletin are devoted to the mining industry of this region. The chief deposits are gold placers and lodes and coal beds. U.

A Geologic Reconnaissance of the Iliamna Region, Alaska. By G. C. MARTIN and F. J. KATZ. Bull. U. S. Geol. Survey No. 485, 1912, 138 pp., with 2 maps.

Copper, silver, and gold deposits are of possible economic importance. Oil seepages occur, but drilling has been unsuccessful.

Preliminary Report of the Coal Resources of the Pikeville Special Quadrangle of Eastern Tennessee. By W. C. PHALEN. Tenn. Geol. Survey Bull. 9, Nashville, 1911, 72 pp.

This bulletin is a cooperative report by the Federal and State surveys. U.

Mineral Production for year 1911 of British Columbia. By WM. FLEET ROBERTSON. Bureau of Mines, Victoria, B. C. Jan. 31, 1912.

The production, which is based partly on estimates, includes $5,120,465 from gold, $4,890,100 from copper, $8,522,500 from coal and $4,678,751 from silver, lead, zinc; coke and building materials. U.

Mineral Production of Ontario for 1911. The Bureau of Mines, Bull. No. 8, Toronto, 1912.

The total metallic production of Ontario for 1911 had a value of $29,097,992. Non-metallic products increased this amount to $41,432,898. Silver constituted more than half of the metallic products, with iron second, nickel third, and copper fourth. Among the non-metals cement, brick, and natural gas are most important. U.

Mineral Resources of the United States. Non-metals for 1910. Pt. 2. U. S. Geol. Survey, 1911. U.

Preliminary Report of the Mineral Production of Canada for 1911. By JOHN MCLEISH. Can. Dept. of Mines, Ottawa, 1912, 23 pp.

The total production for the year as given subject to revision is $102,291,686, a decrease of 4 per cent. from that of 1910. The production is about equally divided between the metals and non-metals. Of the non-metals, coal ($26,378,477) is by far most important. Of

the metals, silver afforded $17,452,128; pig iron $12,306,864; nickel $10,229,623; gold $9,762,096 and copper $6,911,831. U.

Report of the Dept. of Mines of Penn., 1910. Pt. 1, Anthracite; Pt. 2, Bituminous Coal. Harrisburg, 1911. U.

Ann. Rept. of the Dept. of Mines of West Va. for year ending June 30, 1910, 333 pp. Charleston, 1911. U.

Tasmania, Mine Report, 1910, Hobart, 1911, 92 pp.

Tasmania produced in 1910, gold 37,048.05 ounces; silver-lead valued at £247,576; copper valued at £566,972; tin valued at £399,393; coal valued at £48,606; in addition to small amounts of wolfram and bismuth. U.

Preliminary statement of the Mineral Production of Quebec during 1911. Telegraph Publishing Co., Quebec, 1912.

The total value of the production was $8,567,143, most of which was derived from asbestos, cement, limestone, and bricks. U.

Papers and Reports relating to Minerals and Mining in New Zealand. By JOHN MACKAY. Wellington, 1911.

Includes a report of the mining industry in the several goldfields; a paper on the coal mines, and an administrative report. U.

The Mining Industry in North Carolina during 1908, 1909, and 1910. By JOSEPH HYDE PRATT and MISS H. M. BERRY. N. C. Geol. and Econ. Survey. Econ. Paper No. 23. Raleigh, 1911, 134 pp.

The total mineral production in the state had a value in 1910 of $2,848,446 divided in the main as follows: Clay products $1,223,704; stone $920,027; mica $230,460; iron $114,237; talc and pyrophyllite $69,805; and gold $69,586. U.

GENERAL.

Die Geologische Bedeutung des Wachstumsdrucks Kristallisierender Substanzen. By K. ANDRÉE. Geol. Rundschau, Vol. 3, 1912, pp. 7–15.

Gives a resumé of the present status of knowledge concerning the force of growing crystals. A bibliography with 62 titles is added.

Die Metallurgie des Wolframs. By HANS MENNICKE. 416 pp., Berlin, 1911.

A practical handbook on the metallurgy and technical utilization of tungsten.

Magmatic Origin of Ore-Forming Solutions. By C. F. TOLMAN. Min. and Sci. Press, March 16, 1912, pp. 401–404.

Replies to the recent review by A. C. Lawson (Min. & Sci. Press, Feb. 3, 1912) in which the widely held view that magmatic waters are important factors in ore genesis was attacked. Mr. Tolman summarizes much of the evidence bearing on this problem and meets argumentatively most of Mr. Lawson's contentions. U.

The Mineral Sulphides of Iron. By E. T. ALLEN, J. L. CRENSHAW, and JOHN JOHNSTON; with Crystallographic Study, by E. S. Larson. Am. Journ. Sci., Vol. 33, 1912, pp. 169–236.

This paper gives in detail the results of the experimentation on the mineral sulphides of iron at the Carnegie Geophysical Laboratory. Marcasite, pyrite, and pyrrhotite were synthesized in a number of ways. Marcasite is monotropic toward pyrite and can not exist above 450°. Pyrrhotite is of variable composition and is to be regarded as a solid solution of sulphur in ferrous sulphide. There are two crystal forms of pyrrhotite—a high temperature form, which is probably orthorhombic, and a low temperature form, which is hexagonal. Pyrite dissociates at a high temperature into pyrrhotite; the reaction is reversible and is dependent on pressure.

UNCLASSIFIED.

Building Stones and Clays. By EDWIN C. ECKEL. John Wiley & Sons, New York, 1912, 264 pp.

The several varieties of building stones are treated separately, special emphasis being laid on the features of each which enhance or lessen its commercial value. A separate chapter is given to the field examination and valuation of stone properties. Clays are classified according to origin and each class is treated separately. An extensive reference list to the phase of the subject treated follows each chapter. U.

Crystallography, Lecture Notes on. By HORACE B. PATTON. 3d edition, 54 pp. Golden, Colorado, 1911. U.

Earth Features and Their Meaning. By WILLIAM HERBERT HOBBS. The Macmillan Co., New York, 1912. 506 pp., 24 plates, 493 text figures.

A book intended as an introduction to geology for the student and the general reader, this volume is admirably adapted to the use of the mining man and prospector who desires to know the meaning of various land forms. The great number of illustrations are intimately interwoven with the text and greatly augment its value to the non-technical reader. U.

Fertilizer Resources of the U. S. Message from the President of the United States to Congress. Senate Document No. 190, 62d Congress, 2d Session, 1912, 277 pp.

A letter from the Secretary of Agriculture together with a preliminary report by the Bureau of Soils, on the fertilizer resources of the United States. U.

Mineralogy. By F. H. HATCH. 4th edition. Whittaker and Company, New York, 1912, 253 pp. 124 ills. U.

An Unusual Occurrence of the Mineral Evansite. By J. S. GRASTY. Bull. 8, Univ. of Va. Publs. Charlottesville, 1912, pp. 223–230.

Describes evansite, a hydrated alumina phosphate, from a coal bed in Alabama. U.

SCIENTIFIC NOTES AND NEWS[1]

E. N. ZERN, recently professor of coal mining at the University of Pittsburgh, has been appointed professor of mining at West Virginia University, Morgantown, W. Va.

DR. T. A. JAGGER, JR., of Massachusetts Institute of Technology, who has been on the Hawaiian Islands since early in January, instituting a seismologic laboratory, returned to this country in May for the purpose of completing arrangements here preparatory to a residence of five years in Hawaii on seismologic work.

PROFESSOR J. J. STEVENSON requests his correspondents to note that hereafter his address will be 215 West 101st Street, New York.

A. G. MADDREN, of the Alaska Division of the U. S. Geological Survey, left Dawson, Yukon Territory, May 24, on his way to join the International Boundary surveying parties north of Porcupine River.

J. T. PARDEE is making a mineral classification of the land in Colville Indian Reservation, Washington, this summer.

CHARLES BUTTS is spending the month of June studying the subdivision of the Cambrian and Ordovician in central Alabama.

F. B. VAN HORN spent the latter part of May examining phosphate deposits in Kentucky and Tennessee.

D. B. STERRETT, of the U. S. Geological Survey, will study the Appalachian forests in the vicinity of Waynesville, N. C., during June. The purpose of the investigation is to determine the relation of forest cover to runoff in that area.

[1] Geologists, mining engineers and others interested in applied geology are invited to keep the editor informed of new investigations of mining districts or scientific studies undertaken by them, together with such other scientific and personal items as may come to their notice.

A. C. VEATCH, who has been acting as Special Counsel for the Department of Justice in certain California Oil Field cases, has finished the work in California, and went to Tampico, Mexico, the first of June.

E. S. LARSEN left Washington June 7 for Creede, Colo., where he will spend the summer in a continuation of the areal mapping of the Creede Special and Umcompahgre quadrangles.

G. C. MATSON is at present engaged in a study of some of the Louisiana oil pools.

H. D. MCCASKEY, of the U. S. Geological Survey, was in San Francisco the first of June on his way to visit some of the cinnabar deposits of the Pacific Coast.

F. L. RANSOME, who returned from Arizona the first of June, will spend part of the summer in Washington.

MR. WALDEMAR LINDGREN, of the U. S. Geological Survey, has been appointed Head of the Geological Department of the Massachusetts Institute of Technology. He will occupy the chair of the newly established William Barton Rogers research professorship of applied geology.

THE EXAMINATION of coal fields by U. S. Geological Survey parties mentioned in the following lines will be begun within the next few weeks. Several other parties will be examining other coal fields but their plans are not yet definitely settled.

C. J. HARES will map an area in the lignite field in the southwest corner of North Dakota and northwest corner of South Dakota.

E. R. LLOYD will study an adjacent area on the east in both the Dakotas and extending north as far as Bismarck.

EUGENE STEBINGER will continue mapping the areal geology in the Blackfoot Indian Reservation, Montana.

CHARLES F. BOWEN will make a trip from Forsythe, Mont., on the Yellowstone to the mouth of Judith River on the Missouri for the purpose of studying the stratigraphy of the Cretaceous

formations and late in the season will examine a coal field north of the Missouri, opposite the mouth of Judith River.

G. S. ROGERS will begin work in the vicinity of Sheridan, Wyo., and continue north to the vicinity of Forsythe, Mont.

C. M. BAUER will examine a tract north of the Fort Peck Indian Reservation in northeast Montana.

J. S. DILLER, of the U. S. Geological Survey, spent the latter part of May in the vicinity of Easton, Pa., investigating asbestos and talc deposits.

R. W. STONE, of the U. S. Geological Survey, will spend the coming summer in the Flathead Indian Reservation, Mont.

THE PERUVIAN EXPEDITION OF 1912.

The Peruvian Expedition of 1912, organized under the auspices of Yale University and the National Geographic Society for the purpose of carrying on geographic and anthropologic exploration in Peru, will endeavor to continue and extend the work of the Yale Peruvian Expedition of 1911, utilizing the discoveries made then and continuing further along the same lines.

It is proposed to pursue intensive studies in the region where reconnaissance work was done on the last expedition, taking advantage of the discoveries then made to guide the plans for this year.

The expedition will include a geologist, an osteologist, a surgeon, three topographers and three assistants, besides the director. The geologist will be Professor Herbert Gregory, Silliman professor of geology in Yale University, and the osteologist, Dr. George F. Eaton.

MR. ANSEL F. HEMENWAY, of the University of Chicago, has been appointed professor of biology and geology in Transylvania University, Lexington, Ky., to succeed Professor Charles A. Shull who has recently resigned.

T. POOLE MAYNARD, Ph.D. (Hopkins), has resigned as assistant state geologist, Geological Survey of Georgia, and will open an office as a consulting and mining geologist.

HENRY LEIGHTON, formerly instructor in the school of mines, University of Pittsburgh, has been advanced to be assistant professor of economic geology, in charge of the departments of economic geology and ceramics.

HOWLAND BANCROFT announces that he has resigned from the U. S. Geological Survey with which he has been connected since 1907 and will enter practice as a consulting mining geologist. While associated with the survey he was chiefly engaged in investigations for the metalliferous section, examining mining properties in Montana, Washington, Colorado, Nevada, Arizona, California and Idaho. He will make a specialty of economic geology and the commercial possibilities of metalliferous deposits. His knowledge of ore deposits and mining conditions in Peru, Bolivia, Chile and Mexico particularly qualifies him for work in Latin America. His headquarters will be in Suite 730, Symes Building, Denver, Colo., U. S. A. (June 1, 1912.)

THE TENNESSEE ACADEMY OF SCIENCE held its first regular meeting in Knoxville on April 6. The following officers were elected: President, Charles H. Gordon; Vice-President, J. I. D. Hinds; Secretary, Wilburn A. Nelson; Treasurer, Sam M. Barton; Editor, E. S. Reynolds. The next regular meeting will be held in Knoxville on the Friday following Thanksgiving.